ELECTRICAL ENGINEERING

OCTOBER 1948

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

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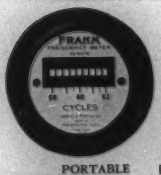

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PORTABLE FREQUENCY METER ▶

▲ HAND TACHOMETER

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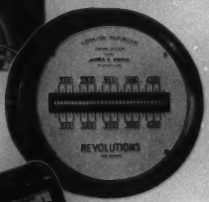

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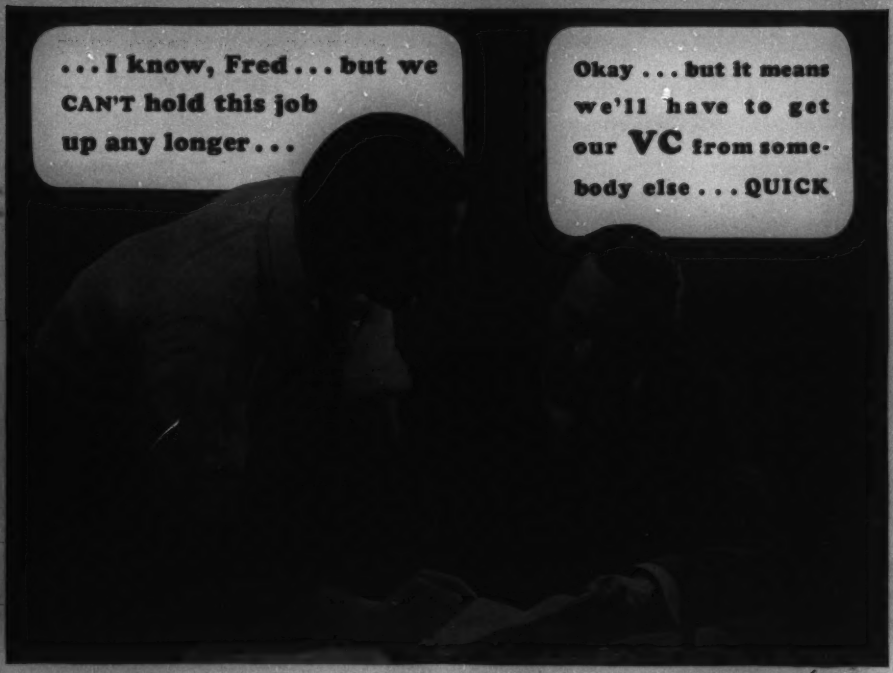

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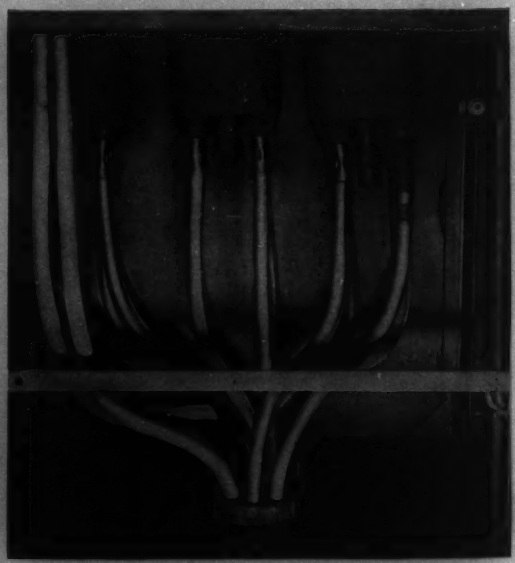

Low side of 4150 volt distribution transformer showing connections of one of the three 208-volt ring mains, in the Bell Telephone Laboratory cellar. This is a 3-phase 203 volt 4-wire system with a pair of circuits passing through each "crab" joint (one phase per terminal). The 4/0 Awg Okolite-Okoprene cables are colored blue, red, and black for phase identification. The two white cables on the left are the neutral conductors. The cables are connected to the crab joint with mechanical squeeze connectors. One of the conductors is in the process of being terminated.

When Bell Telephone Laboratories decided to decentralize part of their engineering facilities by moving into the country, they determined that their new buildings would be built to last "for at least 99 years."

Taking advantage of their own extensive laboratory experience and test results, they wrote specifications that they knew would provide the most durable materials and equipment available.

Their wiring specifications, for instance, called for an oil-base compound protected with a neoprene sheath, where exposures required it. In this new laboratory it was essential to have insulated wire that would resist flame, moisture, heat and chemicals.

The accompanying illustrations show how Okolite-Okoprene cables fitted into the picture and how simple it was to install and splice this carefully-chosen wiring. Okolite-Okoprene cables are used in many other places — in central stations, on railroads, in industrial plants, mines, or wherever long-life and full protection is required and they cost no more than high quality-braided wire. Bulletin OK-2009 describes them in detail. . . . The Okonite Company, Passaic, N. J.

Cooperating on this project were:
Architects and Engineers:
Voorhees, Walker, Foley & Smith, New York
Electrical Contractor:
Hatzel & Buehler, Inc., New York City
Distribution and Power Cables:
The Okonite Company, Passaic, New Jersey

OKONITE

Typical manhole in 4150 volt power distribution line running from substation to Bell Telephone Laboratories. 6 cables on right are 2 circuits of Okolite 3/0 over 11/64" Okolite 4150 volt lead-covered cables supplying power to distribution transformers in laboratory. 2 cables on left are each 7-conductor Okolite-Okoprene signal cables for operating signal light on control board in main building to permit checking position of substation breakers.

3' x 3'—Distribution manhole and distribution panel in cellar of Bell Telephone Laboratory. 14 — 4/0 Okolite-Okoprene cables pass through each manhole — each phase and the neutral are tapped by means of a special split tee-connector. Tap circuit can be seen leaving manhole and entering 208-volt distribution panel. Manhole is carefully waterproofed and cover sealed with a gasket.

Terminal poles on Jersey Central Power & Light Company's main feeder line (13,200-volts) serving Bell Telephone Laboratories substation. 6-single conductor Okonite Varnished lead-covered pole riser cables run from pothead terminals through 4" conduit to substation main line breakers.

3' x 3'—Distribution manhole in Bell Telephone Laboratory cellar showing taps being made on 208-volt ring main distribution cables. These are 4/0 Okolite-Okoprene cables colored for phase-identification. Splicer is making final tap with special split tee-connector. Exposed section of conductor and connector are insulated with Okonite rubber tape and protected with layers of Manson Tape and finally painted with weatherproof compounds. Okolite-Okoprene cables were specified for use in the following tough, damp locations: (1) under cellar floors, (2) between buildings (3) to street lighting standards, (4) at substation, (5) all wiring in kitchen refrigerators, (6) all wiring to outdoor bracket fixtures.

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Phantomized to show closed position ready to operate

Shows indicating position with Fuse Link separated

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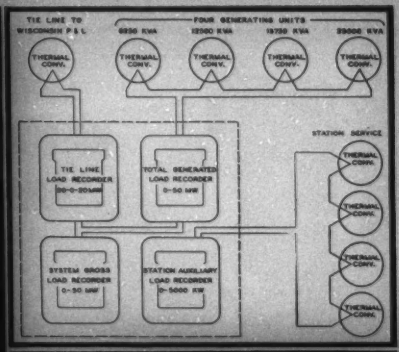
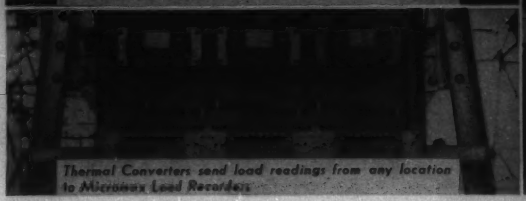
Logging the readings of a typical battery of 4 Micromax Load Recorders. At right is a diagram of these transmitters and recorders.





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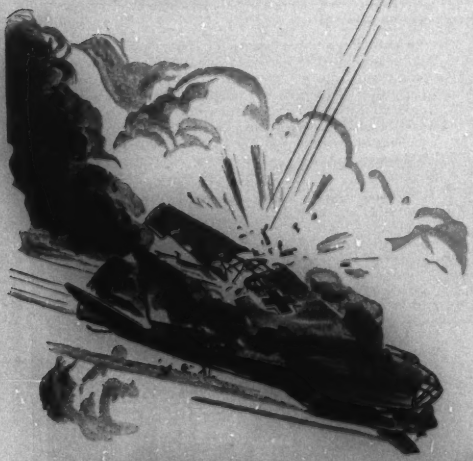

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ELECTRICAL ENGINEERING

Registered United States Patent Office

OCTOBER
1943

The Cover: This 5,000-horsepower electric locomotive, one of several recently installed by the New York, New Haven and Hartford Railroad, is said to represent the most improved design added in a 12-year-old program of providing fast high-powered motive power for the railroad's electrified territory.

General Electric Photo

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Glaze Storms and Electrical Service

E. J. CHRISTIE
NONMEMBER AIEE

H. S. CHARTIER
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The glaze storm which visited eastern New York State in December 1942 exceeded in area covered and weight of ice any previously recorded, according to the authors of this article, one of whom was active in the repair work throughout the storm and restoration period. The effect of the storm on electric-power systems in the area and the conclusions that can be drawn from it regarding heavy loading conditions due to such storms are discussed.

CHRISTMAS 1942 was followed by the most destructive glaze storm that has been recorded in the central eastern part of New York State. This storm started with rain on the 27th, reached its peak on the 30th, and was followed by snow and subzero temperatures. Another similar but lighter storm followed on the 18th and 19th of January with extreme cold on the 21st. It might be well to examine the mechanics of a glaze storm before describing this one.

All weather is caused or occasioned by air masses as they move across the country—at times by the complete domination of one or the other, the warm or the cold—but most often by the action taking place along the zone which separates them. Cold air masses are dome-shaped, and, therefore, the leading and receding edges of them are wedge-shaped as they progress laterally across the country. As warm moist air is forced upward by the leading edge of a cold mass of air or flows up the slope of the receding edge, it becomes cooled, chiefly because of the expansion taking place with a decrease of pressure, and condensation results. Clouds are formed first, and, if sufficient moisture is condensed, particles of either rain or snow will fall to the earth's surface. The leading edge of a cold air-mass dome forms what meteorologists call the cold front surface, since it is along this surface that the cold dense air forces the warm and lighter air to rise, as the cold air invades the region formerly covered by warmer air. The receding edge is called the warm front surface, because here the warm air rises up the slope more or less of its own accord, as it invades the region formerly covered by cold air.

Glaze or ice storms occur with the warm front type of meteorological situation. The cold mass of air itself moving over a locality cools all objects substantially to its own temperature. If the cooling is of such a degree that the temperature of the objects becomes much below freezing, any moisture then deposited on them freezes immediately. Such is the case when ice storms occur. When the cold air is followed by a mass of warm moist air in which water droplets form above the earth's surface, they drop down through the cold air, strike the cold objects, and adhere immediately thereto in the form of glaze. This happens when the layer of cold air is more or less shallow, whereas, when the cold air layer is thick, the water droplets are cooled sufficiently before arriving at the earth's surface, so that they are frozen, in which case the result is frozen raindrops or sleet (Figure 1).

A very cold mass of Arctic air invaded the northeastern part of the country December 26, 1942, driving temperatures far below freezing during that day and night, and most of Sunday, the 27th. Sunday night it was crested over eastern New York State and central and northern New England, so that its receding edge sloped back to the west and south into Pennsylvania and Ohio. A flow of warm moist air had been moving up from the Gulf of Mexico and during the early evening of the 27th it began to ascend the back slope of the hill of cold air. Sufficient condensation took place to cause light drops of rain to fall through to the earth's surface over much of New York State, and a light coating of glaze occurred.

E. J. Christie is chief meteorologist of the United States Weather Bureau, Albany, N. Y. H. S. Chartier is distribution engineer with the New York Power and Light Corporation, Albany, N. Y.

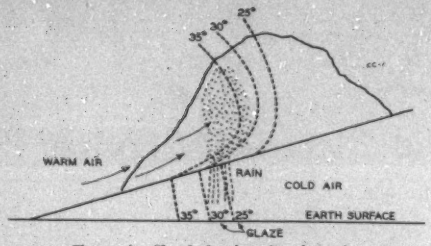

Figure 1. Sketch showing glaze formation

Both air masses kept moving slowly toward the northeast, and the cold mass of air passed on into the Atlantic Ocean area. It was not the end of the freezing rain mechanism, however, for another mass of Arctic air moved southward from the Hudson Bay region on the 28th and slid gently across New York State keeping temperatures down near or slightly under freezing at the earth's surface and providing another slope for the warm air to ascend. The flow of warm moist air from the south continued, and light freezing rain occurred in the eastern half of New York State. On the 29th a definite center of low pressure began to form in the West Virginia area with increasing wind circulation, causing a more pronounced flow of air from the south. During the early morning hours of the 30th this low-pressure area began moving northeastward, intensifying the rain, so that large accumulations of ice resulted, as well as causing the wind to increase. By the next day it had progressed into New England. As soon as the center of this low-pressure area had passed, the winds shifted to the northwest, and colder air once again invaded New York State, but this time the cold front took the upper hand, changing the freezing rain to snow.

The tabulations of temperatures and rainfall given in Tables I and II will assist in an understanding of this storm.

Most of the electrical service to 13 counties in this central eastern area with a population of 785,000 is provided by one public-utility company. This company has 227,000 electric-power consumers along the Hudson and Mohawk River valleys and the adjacent highland. About 86,000 of this total were in the area covered by the storm, and of this number 40,000 were without electric service for periods varying from an hour to, in the most isolated and damaged spots, 17 days.

The affected area is shown on the accompanying map, Figure 2. Contour lines and thickness of glaze are also given. Attention is drawn to the way glaze increased with elevation and to its greater prevalence on the eastern slopes.

Little direct ice damage to lines occurred at elevations less than 500 feet, as up to that height the glaze did not exceed one-half inch in radial thickness. Most troubles in this belt came from falling limbs that caused short circuits on primary lines and burned them down. Interruptions were generally of not more than one or two hours' duration.

Table I. Minimum and Maximum Temperatures

December 27–31, 1942

Station	Elevation	27 Min	27 Max	28 Min	28 Max	29 Min	29 Max	30 Min	30 Max	31 Min	31 Max
Albany	277	4	30	30	34	30	34	31	39	23	31
Cooperstown	1,240	7	32	30	34	32	35	30	37	20	32
Gloversville	850	7	26	26	34	32	34	30	38	20	36
Saratoga Springs	550	0	29	24	35	29	37	30	39	21	40
Sharon Springs	1,360	5	27	27	32	29	32	31	33	19	33
Utica	410	11	31	31	35	32	35	28	39	26	32

In a second zone of elevations between 500 and 1,000 feet glaze was from one-half to one inch in radial thickness. Most of this accumulated during the afternoon and evening of the 29th and the morning of the 30th. The temperature rose to 36 degrees Fahrenheit on the afternoon of the 30th, and with the accompanying warmer rain the ice fell off. Little wire fell from direct ice loading. That which did come down was nearly all numbers 6 and 4 weatherproof copper. Many larger wires were burned off when short-circuited by falling limbs. When the primary wire was 2/0 or larger, even limbs 15 inches through were initially supported by the wire. The conductors were crowded together by the limb causing a short circuit which in most instances tripped the station breaker. The second or third reclosure would burn the wire off, and the whole act would be repeated on the remaining wires. Damage could have been somewhat lessened if all service had been discontinued, and lines killed. Two cities with a population of 35,000 had practically no loads on the stations even though most of the distribution breakers were closed. Interruptions from this cause for the most part were corrected within a 72-hour period after limbs ceased to fall, the speed of the restoration service being subject to the limitation of the man power available.

Services were a source of great trouble in the two cities mentioned. There are 18,000 consumers in this urban and the surrounding rural areas. Over 1,000 services have been replaced and 500 repaired. Where two or three open wires were fastened to a rack on the building, sections of the boards were frequently torn out. If the wires were fastened to single light screw insulators, the building was not damaged, but in either case the conduit

Table II. 24-Hour Precipitation During Period

December 27–31, 1942

Station	27	28	29	30	31	Total
Albany	0.25	0.66	0.57	1.64	T	3.12
Cooperstown	0	1.75	0.44	1.51	1.72	5.42
Gloversville	0	0.97	0.31	1.96	1.09	4.33
Saratoga Springs	0	0.80	0.27	1.70	0.70	3.47
Sharon Springs	0	1.81	1.00	1.81	0.30	4.92
Utica	1.20	0.62	1.36	1.78	0.10	5.06

was often broken and the wires torn out or burned off (Figure 3). Concentric cable services fastened to the buildings with a four-inch or longer screw hook did not fail unless heavy limbs fell across them. The hook then straightened out, releasing the cable from the house without damaging the boards or interrupting service.

Real ice damage occurred at an elevation of above 1,000 feet. The storm started with a cold rain in the evening of the 27th with the air temperature in the upper 20's. By the morning of the 28th limbs had begun to fall and wires to burn off. Glaze had accumulated to a thickness of five eighths of an inch by six in the evening, and it was practically impossible to maintain any service even though 40 men were massed on as short a line as 3,000 feet of the main street of a small town. Work on restoration was discontinued before midnight, as limbs and trees were falling so often that risk of injury to men was excessive.

Glaze continued to build until evening of the 29th, at which time it varied from one to three inches in radial thickness. Lines were crushed from the weight of ice (Figure 4). Highways were so badly filled with broken trees, poles, and wires that state and other road employees used not only saws and axes but even large snow plows in an attempt to keep the roads open for travel.

This situation was followed by eight inches of snow, lowered temperatures, and a wind of 25 miles per hour.

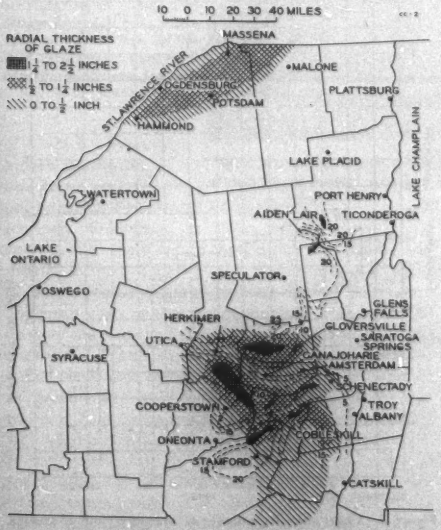

Figure 2. Map of glaze area, eastern New York State, storms of December 28, 1942, and January 21, 1943

---00--- Elevation in hundreds of feet above sea level

Figure 3. Damage at elevation of 1,300 feet where glaze was one-half to one inch in radial thickness (Main Street, Cherry Valley, December 29, 1942)

No melting occurred for more than two weeks, and 30 degrees below zero was recorded.

It was very fortunate that only small towns and rural lines were located in these areas, as interruptions to service lasted from a few hours to as much as 17 days (Figure 5).

Distribution lines in the villages were largely 20 to 30 years old. Spans were short and the conductors were numbers 6 and 4 weatherproof copper wire with a small amount of number 2. Few poles were broken even though many were old; however, all alley arms failed, and much of the wire was down. Except for burndowns, the number 2 wire was for the most part intact, and on this short span construction dead ends held. The rural sections were all less than 20 years old, many built within the last five years, and chiefly of long span type with high-strength conductors.

Typical of the worst damage was a 30-mile section of rural line about 1,500 feet in elevation where there was not a single span of usable line. Six miles of this consisted of number 2 bare copper wire, three-phase on 225-foot spans, the rest of the line was numbers 4A Copperweld and 2 steel reinforced aluminum cable, with a small amount of number 6 solid steel. All of the last three were single phase with spans from 300 to 500 feet in length. Wires had a kidney-shaped section of ice on the tops and sides one and a half inches or more in thickness, and below was a series of icicles from six to eight inches in length so close together as to form a solid sheet. This loading exceeded three pounds per foot in weight (Figure 6).

Seventy poles were broken in this section. Most of these were dead-end or transformer poles. Many more were tipped partially or completely out of the ground and had to be reset. Dead-end poles with short lead guys (under 15-foot lead) were broken in the middle,

Figure 4. Damage at elevation of 1,400 feet where glaze accumulated to thickness of one to three inches (Main Street, Van Hornesville, January 1, 1943)

while those with long lead guys were broken over the point of guy attachment, and some of these latter could be used temporarily for the restoration of service. Transformer poles failed ten feet or so from the top, possibly from recoil when wires broke.

Single crossarms were almost a total loss. In general, the pins split the wood, but in a few instances the arms were broken over the through bolt. Double arms rarely failed on dead ends, but on angles the pins split them badly. Conductors were naturally broken in many places. These were usually tension breaks, and no one type of conductor material showed any superiority. Greatest conductor damage occurred from snow plows where lines were along or across roads. Few guys larger than 5/16 Siemens-Martin broke. A few anchors pulled up, and two rock anchors broke off.

Complete reconstruction was required in these areas. There was little frost in the ground which was covered with from one to three feet of snow. This combination hampered the work, but some caterpillar equipment was available and was utilized to pull pole butts, raise the new poles, and straighten the tipped poles. Deicing conductors was a major operation. Those that fell early in the storm were frozen in a two-inch layer of ice and had to be broken out, in some cases with a pickax. All had to have the ice shattered foot by foot with hammers or heavy clubs.

Over 325 automatic switch operations were recorded during the storm, and 15 transmission lines were out of service for varying periods. Transmission troubles have not been mentioned thus far, but they are intimately involved with the other interruptions, even though they might not have caused an outage because of other sources of supply.

Early in the storm, with only slightly over $1^1/_4$ inches of ice radially, eight *A*-frame towers fell, presumably from breaking of all conductors in one span. Another case of *A*-frame failure on 110-kv line occurred during the second storm, that of the 18th of January, when five failed with dancing conductors after several trip-outs and one burn-off (Figure 8). It is possible that both of these failures were started by rotation of the channel side sections, because of unbalanced forces from broken or burned off conductors. Additional weight is given this theory as the failures were high in the towers, being at or above the middle. Temporary lines were built on wood poles to permit re-use of these lines until new steel could be obtained and erected.

A wood-pole *H*-frame 110-kv line connecting with another utility system was in the area with the heaviest ice loading, and 46 of the structures built with 55-foot class-*A* poles collapsed (Figure 7). Guyed poles broke over the guys while straight suspension structures failed from 5 to 15 feet below the arm which was of steel. There were no arm failures. The wire was number 4/0 copper, and in some instances the ice had a radial thickness of over three inches. This, together with the sheet of icicles, gave a maximum weight of 14 pounds to the lineal foot. Ice loading exceeded seven pounds per foot for several miles. Failures were progressive and occurred on more than one day.

A light 22-kv single-circuit stub-end line feeding one

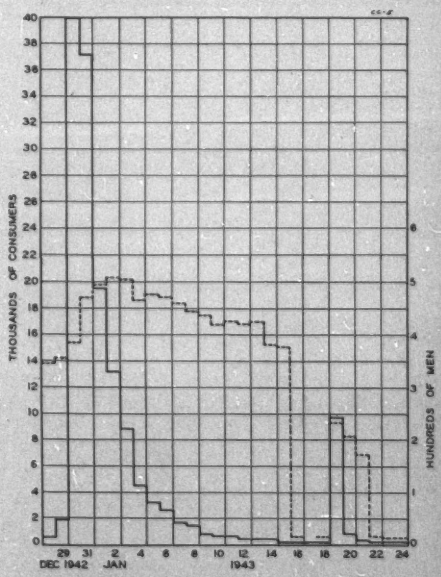

Figure 5. Chart showing number of consumers out of service and number of men required to restore service

——— *Consumers out of service one hour or more*
– – – – – *Men restoring service*

village and rural lines was nearly ruined, having five out of seven miles on the ground with 90 poles broken. Its restoration required 3½ days.

The second storm was of short duration, the glaze building in less than a 24-hour period. It covered much the same area as the first storm, but the maximum glaze did not exceed 1⅛ inches radially. Most trouble was from limbs, many of which were broken during the first storm but had not fallen or been removed. Only in one case was there failure from direct ice loading, and then 20 sections of long-span rural line fell.

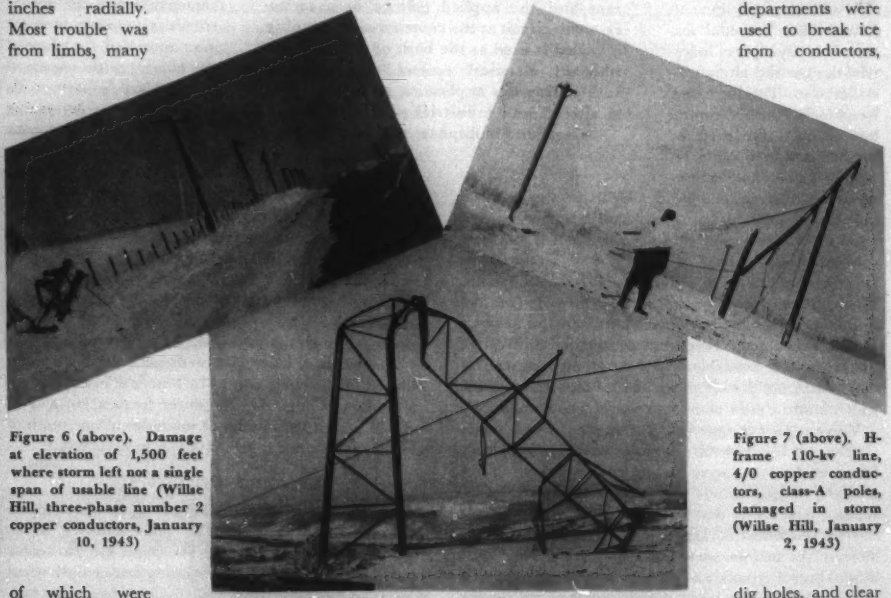

Figure 6 (above). Damage at elevation of 1,500 feet where storm left not a single span of usable line (Willse Hill, three-phase number 2 copper conductors, January 10, 1943)

Figure 7 (above). H-frame 110-kv line, 4/0 copper conductors, class-A poles, damaged in storm (Willse Hill, January 2, 1943)

Figure 8. A-frame tower, 110 kv, 336,000-circular-mil steel-reinforced aluminum conductors, damaged in the storm (Pattersonville, January 18, 1943)

After the rain stopped in both storms, there were numerous cases of dancing conductors, both on transmission and distribution. There was also at least one instance of a rather peculiar phenomenon which the authors have seen only once before—a vertical wave or ripple with a 20- or 30-degree front about six inches high traveling from one support to the next, then reflecting and returning with no discernible change in amplitude. It took approximately one second for the wave to traverse the 200-foot span of three-eighths-inch Siemens-Martin ground wire. The conductors and arms in this section had failed, the pins being torn from the arms, possibly from this cause. The temperature was below zero, 1½ inches radially of ice on the wire, with about a 15-mile-per-hour cross wind.

Needless to say, all normal means of rapid communication were the first to fail. This made necessary the use of a field force that could be depended upon to act for itself. Only trained linemen can restore lines safely under such difficult conditions without serious damage to personnel. Supervision must be of a high type. Laborers drawn from all departments were used to break ice from conductors, dig holes, and clear trees that had fallen. Engineers were used to survey the damage, to prepare lists of material needed, and to keep track of conditions generally. Some who had extensive operating experience were also used to supervise large areas.

Experience in these storms has indicated that modern construction designed to meet heavy loading conditions is, in general, adequate to carry well up to one inch of radial ice where there are no trees. The use of alley arms should be minimized, as even when doubled they fail early. Guys should be attached to the poles at the point of strain and should have a lead of one or more. Storm guying should be at one-half-mile intervals or less and can be installed easily at angles requiring dead ends. More than one primary circuit should not be carried on a pole. Structures, both transmission and distribution, should be so designed that the arm will be weaker than the supporting member. Dead-end structures should exceed in strength all conductors.

Resonant Electrical Control Systems

DAVID WILLIAM MOORE, JR.

The electrical phase shift between the current and the applied voltage in a series-resonant circuit as the resonant-circuit tuning is varied is used as the basis of operation for resonant electrical control systems. The author discusses application of such systems to aircraft and industrial problems, and to single and multiphase radio control.

REMOTE positioning and control equipments have become essential features in many types of industrial designs and aircraft installations. The increasing trend for centralized control has enlarged the need for mechanisms to operate remotely valves and adjustments. In many installations flexible shafts or mechanical linkages are impractical. A flexible shaft cannot be relied upon for accurate control adjustments if it is too long, or overloaded, or made to traverse short radius bends. It is often impossible to design around these limitations. Where space is an important factor it is sometimes desirable to design the equipment into more components than is functionally necessary to permit utilization of space wherever available. This necessitates the translation of shaft positions from one unit to another, a change which must be done with some type of follow-up system.

Various types of electrical, pneumatic, and hydraulic positioning and control systems have been developed. Many of these are accurate and efficient when no appreciable torque output is required. Power-producing systems have been developed, most of which require electric contactors or long pneumatic tubes and thus increase the maintenance and installation costs. Most of the contact types are of the so-called on–off type, and do not produce a control torque proportionate to the input error signal. Such being true, they are susceptible to hunting if adjusted to permit a high sensitivity.

THEORY OF OPERATION

The control system described in this paper depends for its operation upon the phase-shifting characteristics of a series-resonant electric circuit. The system requires no contacts and may be operated over a wire or radio channel. High-torque low-power operation may be had with no electronic amplifiers.

The series-resonant circuit consists of inductance, capacitance, and resistance in series, with the value of the resistance determining the Q, or efficiency, of the circuit. Figure 1 shows the current and current-voltage phase relationship as the frequency of the applied voltage is varied above and below the resonant frequency of the electric circuit. The current is maximum and in phase with the voltage when the circuit is tuned to resonate with the frequency of the applied voltage. As the applied-voltage frequency is changed slightly, the electric circuit is no longer tuned to resonance, and the phase of the current with respect to the applied voltage shifts rapidly, leading or lagging the voltage, depending upon the direction of the frequency change. This phase shift is rapid to approximately 45 degrees leading or lagging and then asymptotically approaches 90 degrees as the frequency change is continued. The rate of change of this phase shift is a function of the efficiency or Q of the electric circuits, being greater for more efficient circuits. Since this resonant control system is operated by a phase-sensitive servomotor, the efficiency of the electric circuits determines the sensitivity of the control and may be designed to a value consistent with the application and cost of the equipment. In practical resonant control apparatus operating on power frequencies, a Q of five will permit sensitivities of the order of one tenth of one per cent change in frequency or in inductance.

BASIC RESONANT CONTROL

Figure 2 is a schematic diagram of the basic series-resonant control system. The phase-sensitive servomotor used here is the simple two-phase electric motor which has the property of developing torque only when there is an electrical phase differential between the currents in the two phases. Maximum torque is developed when there is an electrical phase differential of 90 degrees between the currents in the two motor phases, and the direction of the torque produced depends upon which motor phase has leading current.

The series-resonant circuit in this system consists of the mechanically variable inductances L_1 and L_2, capacitance C_1, and phase one of the motor. The position transmitter of this system is inductance L_3, which may be varied by rotating its control shaft. It is connected to the position receiver by two electric conductors which may be of considerable length. The position receiving section of the control consists of inductance L_2 which is adjusted by the two-phase servomotor. Phase two of the servomotor is connected directly to the a-c power supply and adjusted to unity power factor by any convenient method, so that the current passing through it is in phase with the applied power-supply voltage.

In the stand-by or equilibrium condition, the series-resonant circuit is adjusted to resonate with the applied voltage and in this condition also passes inphase current.

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Therefore, the two-phase motor has unity-power-factor current in each phase, and no torque is developed, because there is no electrical phase differential between the currents in the two motor phases. If the position transmitting inductance L_1 is varied by turning its control shaft, the series circuit is slightly detuned and a shift produced in the phase of the current passing through it. This in turn produces an electrical phase differential between the current in the two phases of the servomotor, causing it to develop torque. This torque is used to turn the control shaft of inductance L_2 until it is adjusted so that the series circuit is resonating with the power-supply frequency and until equilibrium again is established. The servomotor at all times tends toward a condition of resonance in the series circuit by maintaining the sum of the inductance values of L_1 and L_2 constant. Therefore, to permit accurate and linear position repeating it is necessary to design the mechanically variable inductances to change their value linearly with input shaft rotation, and to be complementary units, since the value of the inductance in the position receiver must increase as the value of the position-transmitting inductance decreases in order to maintain the sum constant. Figure 3 illustrates the lamination design which produces this type of inductance change, and shows its simplicity, there being no moving coils and consequently no need for brushes and slip rings. This type of inductance is linear for approximately 70 degrees rotation of the control shaft, and accurate position repeating throughout this range may be obtained. Greater ranges may be had by gearing, with no loss in the percentage of accuracy, or by using different inductance design.

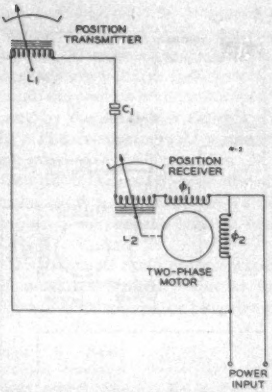

Figure 2. Schematic diagram of the basic series-resonant control system

The sensitivity of this system is very high near the balance point, because the current is rising to a maximum at low electrical phase angles, permitting the development of substantial torques although the phase differential between the currents in the two motor phases is small.

CONTROL SYSTEM INSENSITIVE TO FREQUENCY CHANGE

This basic control is suitable for operation on controlled frequency systems such as a 60-cycle industrial power supply, but would be upset by mobile electrical systems where the frequency of the applied voltage may shift several per cent. This upsetting is caused by the electrical phase shift in the series-resonant circuit produced by the change in frequency of the power-supply voltage, and has the same effect on the system as a change in phase angle caused by a change in the value of inductance L_1.

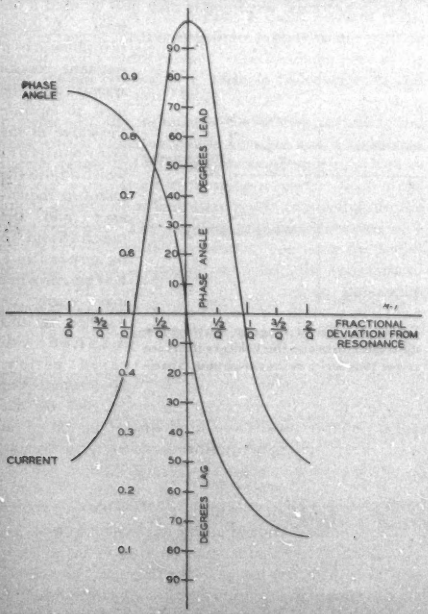

Figure 1. Current and current-voltage phase relationship, as the frequency of the applied voltage is varied above and below the resonant frequency of the electric circuit

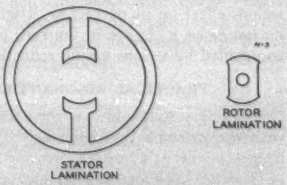

Figure 3. Lamination design which produces inductance changes linearly

A system has been devised which is independent of reasonable changes in frequency and is shown in Figure 4. This system consists of the basic resonant control circuit with a second series-resonant circuit added in phase

two of the two-phase servomotor. The position transmitter in this frequency-insensitive system consists of inductances L_1 and L_3 which are mounted in the same case and controlled by the same control shaft. They are mechanically arranged so that as the value of inductance L_1 is increasing, the value of inductance L_3 is decreasing. This produces opposite electrical phase differential in the servomotor, causing motor torque which adjusts inductances L_2 and L_4, designed as complements of L_1 and L_3, until resonance is re-established. The sensitivity of this system is greater than that of the basic system, since the phase differential in the servomotor for a given inductance change is doubled as a result of two series-resonant circuits being detuned. If the electric-power supply exciting this system shifts in frequency, each series-resonant circuit is affected in the same manner. Equal phase shifts in the same direction in each circuit are produced, causing no electrical phase differential between the currents in the two motor phases. Consequently, this frequency change does not affect the zero, or balance point, of the control. A system of this type will permit a frequency shift of eight per cent with no serious effect on its operation. Higher frequency shifts do not cause a change in the zero position but are accompanied by serious torque reduction.

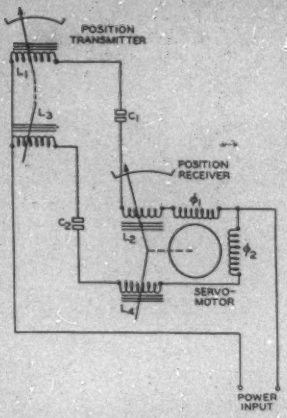

Figure 4. A control system insensitive to changes in frequency

PRACTICAL RESONANT CONTROL

A practical follow-up has been constructed in accord with the principle just described. This unit operates from 110 volts at 60 cycles, drawing a maximum power of 14 watts. The torque output is at least 50 inch-ounces per degree error between the position transmitting shaft and the position receiving shaft, with a maximum torque output of approximately 30 inch-pounds at ten degrees error. This unit tracks the position transmitter within one per cent and is sensitive to at least one half of one per cent change of the maximum angular range. This particular unit has been designed for operation on both 50 and 60 cycles, the value of the resonating condensers being changed by means of a toggle switch to insure maximum efficiency on both frequencies.

HIGH POWER OUTPUT

These position repeating systems are limited in power output since the maximum current drain is in the stand-by, or equilibrium, position. After the maximum allowable stand-by current is reached by a system of this type, greater torques and higher power may be obtained by using different phase-sensitive servomotors than the two-phase motor. Thyratron tubes are logical servomotors since they require little control power for large controlled power. If these tubes are used as phase-sensitive controls for servomotors, large powers may be controlled with moderately sized inductances and capacitances.

If the difference between the voltages across two series-resonant-circuit capacitances, as shown in the vector diagram of Figure 5, is used to control the Thyratron grids, the electrical phase of this voltage will always be the optimum angle for firing the tubes. The phase of this difference voltage, as shown in the vector diagram, does not change with the changing phase of the series currents, but is either leading or lagging the electric supply voltage by 90 degrees, depending upon the phase characteristics of the two circuits. Consequently it may be utilized to fire either one of two Thyratrons to control a suitable servomotor.

Air or hydraulic servomotors may also be used if desired. A direct two-phase-motor resonant control system may be used to operate the valve of the servomotor, which adjusts the followup inductance and the mechanism to be controlled. Large powers may easily be handled in this manner with rapid action. Hydraulic power metered by this system could be used for control surface operation on large aircraft to enable positive positioning, or for the operation of large valves.

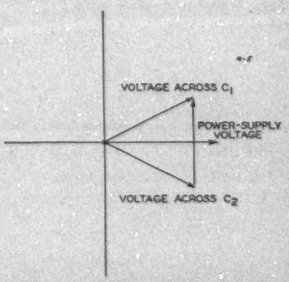

Figure 5. Vector diagram showing the difference between the voltages in phase across two series-resonant-circuit capacitances

TORQUE AMPLIFYING SYSTEM

Figure 6 shows a torque amplifying system suitable for transmitting a low-torque shaft position to an adjacent shaft with increased torque. The resonant control system is a circuit insensitive to frequency changes with the transmitting and receiving inductances combined into one unit. The low-torque shaft varies the position of the inductance rotors, and the servomotor adjusts the induct-

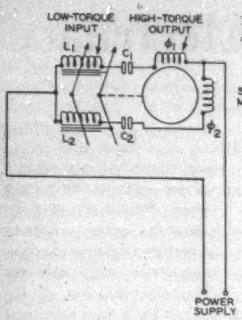

Figure 6. Torque amplifying system for transmitting a low-torque shaft position to an adjacent shaft with increased torque

ance stators, maintaining a resonant condition at all times. Thus a constant mechanical relationship between the stators and rotors of the inductances is assured. This system may be made relatively compact and, with electronic amplifiers, may be made dynamic in action. It is suitable for continuous 360-degree operation.

RADIO CONTROL

All of the systems mentioned so far are suitable for wire operation. Figure 7 illustrates a radio position transmission system capable of definite proportionate position control over a radio carrier. The receiving part of the radio system consists of a variable inductance L_2 and C_2, and a servomotor. Phase one of the servomotor is in series with the inductance and the capacitance, and phase two is made essentially resistive and is connected directly across the alternating-voltage supply, which in this case is the output of the radio receiver. Such a circuit is essentially a frequency meter supplied from the radio receiver. The position transmitter consists of a similar circuit with the servomotor operating an audio-oscillator which is used to modulate the radio transmitter. The transmitter servomotor adjusts the audio-oscillator frequency to the resonant frequency of L_1 and C_1. This frequency modulates the radio transmitter and therefore excites the position receiving circuit, which is adjusted by the receiving servomotor until it is resonating with the applied frequency. If L_1 and L_2 are identical mechanically variable inductances, and C_1 and C_2 are equal, the position of the control shaft of L_1 will be duplicated by the position of the control shaft of inductance L_2. The servomotor in the transmitter is included to permit satisfactory field operation. If the audio-oscillator drifts during warm-up, or at any other time, the servomotor corrects the drift since it maintains the oscillator frequency equal to the resonant frequency of the circuit L_1C_1.

Multichannel radio control may be obtained with the aforementioned radio circuit by assigning a frequency band to each control, or by assigning all of the controls

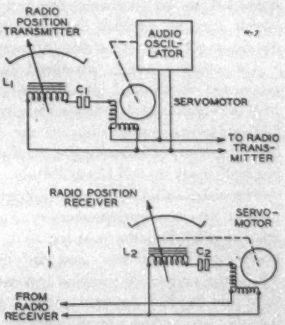

Figure 7. Radio position transmission system capable of definite proportionate position control over a radio carrier

to one frequency band and modulating different subcarrier frequencies with each separate control, filtering them at the receiving end. The carrier system is more satisfactory for a large number of channels, and the individual frequency band system is applicable for the operation of two to four channels. Any type of vehicle could be controlled positively by this system because the control is continuous and not intermittent or based upon a step-by-step arrangement.

Photo courtesy of Pan American World Airways

Sweden Increases Use of Electricity

AAKE RUSCK

Sweden finds the answer to an increased demand for electric power in the intensified development and expansion of water-power facilities and the reduction of steam-power production dependent on imported coal.

PRODUCTION of electricity in Sweden is based mainly on water power. This condition is quite natural, since the country has great natural resources of water power which can be developed, whereas it has almost no domestic coal. The war and the consequent drop in imports of coal have led to an increased demand for electric power which can be satisfied only through the intensified development and expansion of water-power facilities.

The electric energy produced in Sweden in 1914 amounted to about 1,500,000,000 kilowatt-hours. By 1941 the electric energy output had reached 9,300,000,000 kilowatt-hours. According to the 1938 statistics the individual power consumption in Sweden was two and one half times that in Great Britain.

The distribution of Sweden's electric power before the present war is demonstrated in Table I. From the table it is evident that not less than 80 per cent of the power production was used for industrial purposes. The pulp and wood-working industries required more than one third of the total output; the iron and metal industry was a close second, using more than one fourth of the total output.

Sweden's steam-power production before the war was equal to only about ten per cent of the total electric-power production. Of this, more than one half was so-called "back" pressure power, which can be generated by industries having a fairly large need of steam for heating purposes with relatively small use of coal. Steam power, as well as the comparatively modest production of Diesel power, was required chiefly as a reserve and as a complement to the water-power supply at times of high-power consumption and at low-water periods. A certain portion of steam power was produced through the use of waste products of various industries, such as sawdust and furnace gas, but the principal production of steam power was from imported coal. One of the most important problems of power production after the outbreak of the war was the reduction of steam-power production to a minimum in order to save coal.

The outlook for the power supply at the beginning of the war was favorable because a relatively large production apparatus was dependent on imported coal only to a limited extent. Also, large power stations were then under construction. A widespread high-voltage network connected the country's various sections with each other. Practically all of the country's power stations interchanged power continuously over this network. The electrification of the cities and other municipalities had for a long time been 100 per cent effective, and almost three fourths of the rural households had been electrified by 1939.

Of great importance, also, was the expansion of power-production facilities during recent years, which has been undertaken as a precautionary measure in case of war. A central organization, created to manage the production and distribution of power between the larger power enterprises in the country—national, municipal, and private—had been established wholly through voluntary co-operation, and immediately after the outbreak of the war it began to function. The existing power situation was kept under constant survey by a special national bureau, and the power apportioned according to maximum efficiency in utilization. Through such action it has been possible to satisfy the greatly increased need for power, while at the same time the required portion of steam power was reduced to a minimum of what it had been before the war.

It was evident as early as the autumn of 1939 that new and larger power plants were required. The construction of such plants was begun by the government, by municipalities, and by private enterprises. During the first three years of the war, power stations were added with an aggregate annual production capacity of 1,800,000,000 kilowatt-hours, and during the next two years, it is estimated, new plants with an additional total of 2,200,000,000 kilowatt-hours will be completed. The annual increase in power made possible through these extensions is almost 75 per cent greater than the annual increase during the preceding ten-year period. Most of the new stations will be finished in record time.

Table I. Distribution of Water Power in Sweden Prior to 1939

Channel	Per Cent
Trades, agriculture, households, and illumination	11
Railways and streetcars	9
Mining and metal industries	27
Wood, pulp, and paper industries	36
Chemical–technical industries	7
Other industries	10
Total	100

Aake Rusck is manager of the operating department of the Royal Board of Waterfalls, Sweden.

An example of rapid construction is one large power plant which was begun early in 1940 and started to deliver power in October 1941.

Through modernization and improvement of existing power stations, additional power gains have been obtained. As a result of the vastly extended lake-level regulations, it has been possible to increase greatly the accumulation of water in natural lake reservoirs during periods of plentiful rains for later use when the demand for power becomes higher and the rainfall less.

The establishment of lake-level regulations generally requires lengthy court proceedings. At the request of the water-power producers, the Riksdag, or national parliament, in the autumn of 1939 initiated and passed, within a few weeks, a new law by which court proceedings regarding lake-level regulations during war or danger of war were very much simplified. As a result of this law, it has been possible to effect an increase of over 55 per cent in the natural lake reservoirs.

The steps taken for the expansion of the water-power production apparatus so far have proved successful. After the German occupation of Norway and Denmark there was a temporary decline of power consumption as a result of the export industries being barred from their markets in England and America. This decline, however, has been more than compensated for by the increased use of power for other purposes. The present power production is the largest in the nation's history, and the increase in consumption shows a tendency to continue at a rapid rate.

Such a rise does not seem to depend on a large industrial production, but rather on the increased use of electric energy as a substitute for imported fuels for power and heating. This is quite natural, since the imports have been severely reduced. Moreover, the price level for electricity has been held almost constant, whereas the cost of imported fuels and substitute fuels has risen to several times the former level. The competitive power of electricity has thus improved.

Increased use of power in households for electric cooking and heating, among other things, has added also to the rising power consumption. So has the rural power demand, which has grown rapidly as a consequence of government subsidies and of the shortage of oils for lighting and heating. The scarcity of copper, however, may slow up electrification of rural districts.

The electrification of Swedish railways, principally those owned by the government, has continued during the war years. Almost half of the total track mileage of these railways has been electrified. However, since it is principally the railways with heavy traffic that have been electrified, transportation on the government's lines is handled by electric power up to 85 per cent of the total volume. It has been estimated that the electrification of the railways so far completed has resulted in a saving of about 800,000 tons of coal annually. Railway electrification is of enormous importance to Sweden in these times, when transportation on the country's highways is difficult owing to the lack of oil and rubber. Even electric-trolley bus lines have been pressed into service during the last years.

From the point of view of national sufficiency, Sweden will find advantageous the expansion of power production called forth by the exigencies of war.

Transformer and switch house (above) of the government-owned and -operated Porjus water-power station north of the Arctic Circle in Sweden

(Below). The generating room of the Porjus hydroelectric station in Sweden, blasted 165 feet below ground level to guard against freezing

Professional Aspects of Engineering

HERSCHEL H. ALLEN

A consulting engineer presents his idea of the place the engineering profession should occupy in the community. The engineer's relation to his fellow men, particularly to those involved in the economic development of public improvements and industrial enterprise, and the future of engineering as a profession are important aspects of the article.

ENGINEERING in the industries, in public utilities, and in public work is so intertwined with the legal profession and with the business of government and finance that it is sometimes difficult to draw a line of demarcation where the functioning of one leaves off and another begins. The development of this interrelationship in recent years is largely responsible for the increasing professional status of the engineer. The engineer's work in the eyes of the public—and therefore his professional status—are established by the manner of his dealing with his fellow men—with other engineers, bankers, lawyers, and public officials, whom he contacts in the performance of his professional duties, and with his employer or client.

Finance is the key to public improvements and industrial and utility developments in which the engineer plays an important role. In the division of finance called "New Capital Issues," used for the development of industry and utilities, and the development and conservation of natural resources he has a leading part, and the lawyer and the financier fit their contributions into the plan in order to accomplish what the engineer has envisioned. In this form of finance public officials play a secondary part, because such financing and developments are considered to be private business.

In public finance which make available funds for governmental work by one or more forms of taxation, public officials play a leading role. Next of importance in public finance comes the lawyer because of the legal involvements surrounding public finance and governmental work in general. The roles of the financier and the engineer in public finance are secondary. The former merely bids for the public securities and markets them usually at a small margin of profit, and the latter exercises his technical skill in the preparation of the plans and the supervision of construction, and performs other engineering services necessary to effect the transition from authorized municipal-bond issue to completed public improvement.

Too frequently in the past, financing of private industry and governmental work has been done with too little engineering. The application of sound engineering principles is essential in both instances for the real success of completed developments. Revenue-bond financing on the other hand has been less neglected in this respect for the reason that it is relatively new, although the principle involved is old. This form of financing has been developed within the last 15 years, since engineers have been more active in public affairs, and particularly in the recent past while engineers have taken part in adapting this method of financing to various types of publicly owned facilities. It is applicable to all improvements of a self-liquidating nature. It is a method of financing public works privately through the establishment of a governmental agency to sponsor the revenue-bond issue. Here, the engineers' responsibility is greatest of all. The entire success of a revenue-bond project depends upon the reliability, integrity, and honesty of the engineering reports which form its basis. Here, bonds are sold, and funds are made available for construction purposes when sufficient faith and confidence in the minds of all parties has been established.

Such financing is equitable, in that, the self-liquidating aspects of appropriate projects are developed on the principle that one who uses the resulting facility shall pay for it, but the taxpayer, who has not benefited through its construction, is not taxed for its support. Here, solemn covenants are entered into between the governmental body, authorized by law to issue the revenue bonds, and a trustee, who holds the funds and is responsible for their disbursement. These covenants are usually contained in a document known as a trust indenture. Although the engineering responsibility in such projects is very great, the responsibility of all the others in the covenant is also great, and fullest co-operation between them all is vital to the success of the project. Here, it is necessary for the engineer to understand the law and financing elements for the co-ordination of which he is primarily responsible. Here, also the banker and the lawyer must understand enough of each other's business and enough engineering to assist in bringing about the co-ordination and co-operation which is necessary. And here, the engineering profession has been advanced by new steps toward its rightful place beside the older and more established professions.

DEVELOPMENT OF ENGINEERING IN UNITED STATES

It has been said, "The early engineer in this country was a species of scientific or skilled tramp with a pre-

Essential substance of an address delivered before the AIEE Maryland Section March 1, 1943.

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carious tenure of position, measured by the work in progress. He furnished his employer with the skill of his trade without questioning public policy or the best solutions." The transition since then has been slow indeed. The first engineering degree in the United States was conferred in Troy, N. Y., at Rensselaer Polytechnic Institute, in the year 1835. The United States Military Academy at West Point had been teaching science and its application to the military art since the Revolutionary War, and feeble attempts at technical instruction for civilians had been made under Benjamin Hale at Bowdoin College in Maine as early as 1822, but the "application of science to agriculture, domestic economy, the arts and manufactures," as initiated by Stephen van Rensselaer, in 1824, marked the beginning of engineering education in the United States.

In parallel with the industrial trend following the Civil War, engineering courses were started in many colleges and universities. In the 1860's, the number increased rapidly because of the creation of "land-grant colleges" in 1862.

The name "civil engineer" came into usage to differentiate it from military engineering. The offshoots of mining and mechanical engineering were formed in the 1860's of electrical engineering in the 1880's, and of chemical engineering in the 1890's. Today, there are two score offshoot courses in engineering taught at more than 150 engineering schools. These courses now combine scientific, technological, and humanistic subjects. Many have initiated the individual method of laboratory instruction and shopwork. The past 65 years in the development of engineering education have marked an accelerated rise in the status of the engineering profession.

ENGINEERING SERVICES VARIED

Engineering services are numerous and diversified. They are scientific and technical and even extend to the creation of the tools which the scientists themselves use for the discovery of new scientific facts for application by engineers to new uses. They deal with construction problems in all the intricate phases of the modern construction industry. Each new scientific discovery creates some new type of industry required to adapt it to the uses of mankind. Other services include the development and conservation of natural resources and the creation of new public utilities and the extension of existing utilities to provide for the constantly increasing population of our metropolitan areas and industrial communities. Engineers are responsible for the planning of public works and their ultimate financing, construction, and completion.

All of these diversified services require extended contacts on the part of the engineer. The first contact the young engineering graduate makes is his business relationship with his employer. As he gradually develops a professional consciousness, he extends his contacts with his fellow man, and shortly, almost before he is aware of it his interests have been extended in many directions, and he has undertaken wider and more varied problems.

In recent years the management of industries and utilities has been done by engineers trained especially for the work. More recently this has opened a professional-management field with many openings for highly trained capable professional engineers.

Like most of the other professions, the engineer's professional status is unaffected by the terms of his contract; it is outside of and entirely beyond the business relationships which exist between him and his employer. Prerequisite qualifications for successful professional engineering include courage and honesty, both intellectual and moral, which are not concerned with whether his compensation for his technical knowledge consists of a monthly salary or a lump sum fee. Fairness, sound-judgment, and resourcefulness are needed in order to develop a truly professional status. Perseverance, ability to observe closely, accuracy in one's thinking, the drawing of logical deductions and conclusions from the analysis of situations and conditions, and ability to co-operate with others and organize one's work, assistants, and staff are matters beyond the realm of technical training. They embody the extra punch needed to realize the advanced place in society for which all engineers have striven for many years. They are those qualifications needed for conducting one's personal contacts with financiers, lawyers, and public officials, as well as with one's employers and clients, that mark the engineer as a proper recipient of the special privileges extended by society to the professional man. Every engineer who can call these characteristics his own is on his way to the top of his profession and to recognition in the community.

Willard Chevalier has said, "There is something bigger, more vital, and more fundamental in professional relationships than you can write into a statute." This statement was made because of the intense campaign for professional status which has taken the form of legal registration in many of the states during the last few years. The truth of Mr. Chevalier's statement is becoming increasingly apparent to most engineers. Among engineers there exists, now, a better recognition of the distinction between technology and the wider comprehension prerequisite to a professional status.

The possession and practice of a high order of technical skill do not in themselves make an individual a professional man. Technical training alone is merely vocational, rather than professional. The difference between technical training and professional education is a matter of spirit and ideals, even more a matter of a certain supercharge in the man beyond the mere ability to accomplish the day to day tasks of life.

PROFESSIONAL TRAINING

Professional education for the lawyer means more than training himself to prepare legal documents or to try

cases in the courts. It encompasses studying history, philosophy, and the social institutions out of which the law has developed. Legal education began in this country, in 1784. Prior to that time, colonists desiring legal training studied in England. From then until 1829, when college training of lawyers began in this country, law students were taught by a system known as "apprentice training." College teaching continued for about 50 years prior to 1880, before the scientific study of jurisprudence was started. The complexity of governmental functions and the passage of the multitudinous laws which are being ground out in our legislative halls in all the states and in Washington would indicate that the education of lawyers may, in the near future, have to start a fourth phase. At the present time, there is about one lawyer for each 1,000 inhabitants in this country. There are two schools of thought as to the proper method of controlling the personal qualifications and standards to be maintained in the legal profession. In the older jurisdictions, a rigorous course of preparation is advocated to promote competency and character among the lawyers. In the younger jurisdictions, democratic idealism is preferred, and almost all oppose making requirements for preparation unduly difficult.

The engineering profession may never be confronted with a similar problem. The rapid recent advances of technology, the kaleidoscopic changes effected by new scientific developments requiring revolutionary changes in methods of production all contribute to an increasing need of technologists and technicians. If this advance is continued during the period following World War II at the rate it has maintained since World War I, it appears that no sort of restrictive measures will be needed for the selection of the individuals to whom engineering will be taught. On the other hand, preliminary training preceding technical education may have to be intensified to produce technically trained engineers equal to the wants.

We have seen the reverse of this situation during the last few years. The technical training of many of our engineering graduates during the early 1930's has slipped away from the individuals and has been lost to society completely as a result of the inability of these young engineers to practice their technique and continue the assimilation of knowledge so essential to the development of true engineering.

Professional education for the engineer means not only gaining skill in the application of the sciences and mathematics, but also philosophic insight into the sciences and their application to human needs and advancement. The professional status involves a knowledge of social forces and institutions which will enable one to view his work and its consequences not only as a service to employer or client, but also in terms of its benefits to society.

THE ENGINEERING ATTITUDE

There are too many engineers with a narrow and petty attitude about matters of sharing knowledge and advances in professional practice. An engineer's skill is his personal possession, and when he imparts it to another he rightly expects a reasonable remuneration. His knowledge, however, is a part of a common fund which has been passed down through the years, which he shares with others, and to which he is obligated to add, personally, if he possesses the ability—if not, then through the medium of the Founder Societies and other engineering organizations which have been created for preservation and dissemination of professional knowledge.

The difference between a technical vocation and a profession is the supercharge of personality and powers of expression to fit one for a place of influence in the community.

To those men who have been left on the station platform when the train pulled out, who do not see beyond the results of today's work, whose jobs are sources of livelihood only, the attainments of others are often subjects of envy. These men have let their scientific training slip away after college days; they contribute nothing to advancement and exert little or no influence in their communities. But their case is not as hopeless as it sounds, for few men do not display unsuspected personal charms when exposed to conditions which bring out the best in them. It is entirely up to them; all that is needed is the extra will to do.

The daily routine of members of many other professions compels them to study continuously. These are what might be termed contemplative vocations. An engineer, however, leads a life of action rather than one of research and consequently is not given to continuous study. The added drive is therefore much more essential in his case than in other professions. But far too many engineers rely on ordinary experience for the assimilation of additional knowledge without definite mental discipline.

ENGINEERING FUTURE

The future of the engineering profession depends upon its members who not only can produce technical results and business profits, but who can be looked to for the advancement of improved methods and products—men who can be trusted with confidences between agent and client and who can help to shape the policies which guide our future development. Leadership in engineering as in other fields is for men who can combine determined action and intellectual advancement.

During the years to come it seems to me inevitable that industry will be flung to the far corners of the earth. Production will be developed more and more scientifically, and with it all research will expand into ever wider fields, and engineers will increase in numbers and in ability to meet the call. And so, when one asks: "What place does the engineer occupy in civilization?" the reply is not just the turbine, dynamo, bridge, or highway, and not even just the broader relationship as concisely expressed by Karl T. Compton: "Science

seeks to understand nature while engineering seeks to control nature." To this it should be added that other engineers, his employer and client, the banker, lawyer, and politician form the engineer's field of human contacts, and the breadth of his relationships form the yardstick to measure his professional status and worth in the community.

The past 100 years of engineering accomplishment is an unparalleled record. It has, of course, been brought about by contemporary scientific advancement. But the changes in educational procedure, the enlargement of the field to include an ever increasing number of specialties, and the strides made toward reaching the goal of public acceptance point to the near future when engineering will occupy the same honored place in society as the other professions, a goal toward which engineers have been striving. It is our duty to supercharge ourselves and put in the extra punch needed to reach this goal.

Refresher for Dielectric Calculations

E. W. GREENFIELD
MEMBER AIEE

In making dielectric calculations, it is important to be able to correlate the fundamental characteristics of the dielectric material with measured quantities such as current, loss, power factor, and capacitance. In this article the author has attempted to co-ordinate in a simple manner all the relations necessary to dielectric computation.

MANY experimenters faced with measurement on insulation materials for the first time or having only an occasional necessity for dielectric measurements find the literature somewhat scattered and confusing with regard to terminology, relationship of basic concepts, and calculation of results.

The two fundamental characteristics of any dielectric material are

1. Equivalent conductivity (or its reciprocal, resistivity).
2. Dielectric constant.

The relative magnitude of these properties and the manner in which those magnitudes change with variation in applied potential, frequency, temperature, and so forth, completely describe the material from every standpoint. Electrical measuring instruments, in general, do not measure directly the fundamental material characteristics. It is therefore important to be able to correlate these with the measured quantities such as current, loss, power factor, and capacitance, and also to be able to interpret these parameters in terms of the unavoidable geometry of the electrode measuring system.

The equations presented here attempt to co-ordinate in a simple manner all the relations necessary to dielectric computation. These relations have accumulated in the author's notebook for the past several years. It is possible that others may find them as useful as he has.

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CAPACITOR-RESISTOR REPRESENTATION

The appendix contains a general summary of all dielectric terms for any insulating material which can be represented by a simple parallel capacitor–resistor scheme. Such circuit representation applies to all types of capacitor and cable systems, when the frequency is sufficiently low so that series resistance and inductance of the leads and of the electrodes themselves are negligibly small.

The relations are derived in the practical system of electromagnetic units and permit maximum convenience in correlating the various factors. The equations assist conversion of such readily measurable quantities as voltage, current, dissipation factor, and capacitance, to the more basic parameters which characterize the dielectric material itself. The procedure may also be reversed as occasion demands.

The importance of the two basic characteristics of a dielectric, that is, conductivity and dielectric constant are clearly brought out by equation 44 or 45. It is

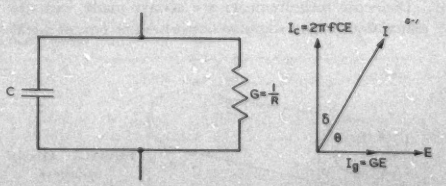

Figure 1. Equivalent circuit and vector diagram of dielectric

Table I. Geometric Capacitance, Conductance, and Resistance for Parallel Plates*

System Dimensional Units	Capacitance, C_o			Conductance (Mhos) G_o	Resistance (Ohms) R_o
	Farads	Microfarads	Micro-microfarads		
Centimeters	$8.85\times10^{-14}\frac{A}{t}$	$8.85\times10^{-8}\frac{A}{t}$	$8.85\times10^{-2}\frac{A}{t}$	$\frac{A}{t}$	$\frac{t}{A}$
Inches	$2.25\times10^{-14}\frac{A}{t}$	$2.25\times10^{-8}\frac{A}{t}$	$0.225\frac{A}{t}$	$2.54\frac{A}{t}$	$0.394\ \frac{t}{A}$
Feet	$2.70\times10^{-13}\frac{A}{t}$	$2.70\times10^{-7}\frac{A}{t}$	$2.70\frac{A}{t}$	$30.5\frac{A}{t}$	$3.28\times10^{-2}\frac{t}{A}$
Mils	$2.25\times10^{-17}\frac{A}{t}$	$2.25\times10^{-11}\frac{A}{t}$	$2.25\times10^{-5}\frac{A}{t}$	$2.54\times10^{-8}\frac{A}{t}$	$3.94\times10^{7}\frac{t}{A}$

*See Figure 2.

shown that as far as the dielectric material itself, dielectric loss is entirely a function of conductivity alone; whereas, wattless power (charging current) is entirely a function of dielectric constant. All other characteristics, such as power factor, dissipation factor, and loss factor, are

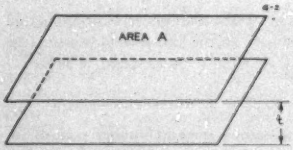

Figure 2. Parallel plates
See Table I

arbitrarily defined ratios which sometimes have more practical advantage when dielectric quality is being interpreted.

The two characteristics of any dielectric system which are of greatest practical importance to the user are

1. The total current drawn.
2. The total watt power consumed.

From a knowledge of the conductivity and dielectric constant of a given material, one calculates the specific current (equation 45) and the specific loss (equation 55). To determine the total current and dielectric loss for any particular capacitor or cable size operating at any given voltage, it is then only necessary to multiply the specific current and specific loss by the appropriate geometry and voltage factors.

INTERPRETATION OF ELECTRODE GEOMETRY

Dielectric measurements are always made with the material under investigation between some type of metallic electrode system. Hence, measurements on dielectrics always yield the parameters, conductance (or resistance) and capacitance, which are functions of both the fundamental material characteristics and the extent and geometry of the particular electrode system. The geometry of the electrode system is generally made as simple and regular as possible but at times may be very complex.

To eliminate the influence of the electrode system from the measurement, one divides the measured conductance or capacitance by an appropriate geometric factor; the result is conductivity or dielectric constant, both of which are peculiar to the material alone. Conversely, these material properties are in such unit form that, when they are multiplied by the suitable geometric factor relating to any contemplated electrode system, total conductance (or resistance) and capacitance are obtained.

The appendix also presents in a systematic manner the equations for these geometric factors appropriate to any

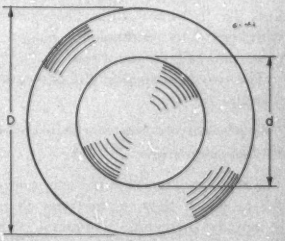

Figure 4. Concentric spheres
See Table III

desired electrode system. Tables I through IV, therefore, supplement the equations relating to a simple dielectric. In effect, the equations given in these tables enable one to determine the C_o, λ, and ρ required in the equations of the appendix.

It should be noted in particular that the geometric factors relating to conductance and resistance are treated in exactly the same manner as for the more familiar geometric capacitance. This makes for a consistency which has generally been lacking.

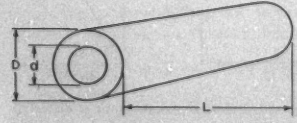

Figure 3. Coaxial cylinders
See Table II

Table II. Geometric Capacitance, Conductance, and Resistance for Coaxial Cylinders*

System Dimensional Units	Capacitance, C_o			Conductance (Mhos) R_o	Resistance (Ohms) G_o
	Farads	Microfarads	Micromicrofarads		
Centimeters	$2.42\times10^{-12}\frac{L}{\log D/d}$	$2.42\times10^{-6}\frac{L}{\log D/d}$	$0.242\frac{L}{\log D/d}$	$2.73\frac{L}{\log D/d}$	$0.366\frac{\log D/d}{L}$
Inches	$6.14\times10^{-12}\frac{L}{\log D/d}$	$6.14\times10^{-6}\frac{L}{\log D/d}$	$0.614\frac{L}{\log D/d}$	$6.94\frac{L}{\log D/d}$	$0.144\frac{\log D/d}{L}$
Feet	$7.36\times10^{-11}\frac{L}{\log D/d}$	$7.36\times10^{-5}\frac{L}{\log D/d}$	$7.36\frac{L}{\log D/d}$	$83.3\frac{L}{\log D/d}$	$1.20\times10^{-2}\frac{\log D/d}{L}$
Mils	$6.14\times10^{-15}\frac{L}{\log D/d}$	$6.14\times10^{-9}\frac{L}{\log D/d}$	$6.14\times10^{-3}\frac{L}{\log D/d}$	$6.94\times10^{-3}\frac{L}{\log D/d}$	$1.44\times10^{5}\frac{\log D/d}{L}$

*See Figure 3.

Appendix

Every dielectric is characterized by a conductivity, λ, and a dielectric constant, ϵ'.

Conductivity, in general, varies with temperature and frequency. Its component due to ionic conduction is little dependent on frequency. Its component due to absorption losses (polar interfacial, and so forth) is dependent on both frequency and temperature.

Dielectric constant, in general, varies with temperature and frequency. Its component, arising from normal polarization of the dielectric, varies with temperature in a manner roughly directly proportional to change of specific gravity. It generally decreases with frequency. Its component, arising from dielectric absorption, varies with temperature and frequency and exhibits anomalous dispersion at regions of absorption maxima.

FORMULAS FOR DIELECTRICS (SEE FIGURE 1)

All units are the practical units, that is, watts, volts, amperes, ohms, mhos, farads, and so forth.

Capacitance $C=\epsilon' C_o$ (1)

Geometric capacitance $C_o=\frac{C}{\epsilon'}$ (2)

Dielectric constant $\epsilon'=\frac{C}{C_o}$ (3)

$=\frac{\epsilon''}{\tan\delta}$ (4)

$=\frac{1}{2\pi fC_o}\cdot\frac{G}{\tan\delta}$ (5)

$=\frac{1.8\cdot10^{12}}{f}\cdot\frac{\lambda}{\tan\delta}$ (6)

Loss current $I_g=GE$ (7)

$=2\pi fC_o\epsilon''E$ (8)

$=11.3\cdot10^{12}\cdot C_o\lambda E$ (9)

Charging current $I_c=2\pi fCE$ (10)

$=2\pi fC_o\epsilon' E$ (11)

Conductance $G=\frac{I_g}{E}$ (12)

$=2\pi fC_o\epsilon''$ (13)

$=2\pi fC\tan\delta$ (14)

$=11.3\cdot10^{12}C_o\lambda$ (15)

$=\frac{P}{E^2}$ (16)

Conductivity $\lambda=0.556\cdot10^{-12}f\epsilon''$ (17)

$=0.556\cdot10^{-12}f\epsilon'\tan\delta$ (18)

$=\frac{1}{11.3\cdot10^{12}C_o}\cdot\frac{P}{E^2}$ (19)

$=\frac{1}{11.3\cdot10^{12}}\cdot P$ (20)

Resistance (insulation) $R=\frac{1}{G}$ (21)

Resistivity $\rho=\frac{1}{\lambda}$ (22)

Power factor $\Delta=\cos\theta$ (23)

Table III. Geometric Capacitance, Conductance, and Resistance for Concentric Spheres*

System Dimensional Units	Capacitance, C_o			Conductance (Mhos) G_o	Resistance (Ohms) G_o
	Farads	Microfarads	Micromicrofarads		
Centimeters	$0.556\times10^{-12}\frac{Dd}{(D-d)}$	$0.556\times10^{-6}\frac{Dd}{(D-d)}$	$0.556\frac{Dd}{(D-d)}$	$6.28\frac{Dd}{(D-d)}$	$0.159\frac{(D-d)}{Dd}$
Inches	$1.41\times10^{-12}\frac{Dd}{(D-d)}$	$1.41\times10^{-6}\frac{Dd}{(D-d)}$	$1.41\frac{Dd}{(D-d)}$	$16.0\frac{Dd}{(D-d)}$	$6.26\times10^{-2}\frac{(D-d)}{Dd}$
Feet	$1.70\times10^{-11}\frac{Dd}{(D-d)}$	$1.70\times10^{-5}\frac{Dd}{(D-d)}$	$17.0\frac{Dd}{(D-d)}$	$1.92\times10^{2}\frac{Dd}{(D-d)}$	$5.22\times10^{-3}\frac{(D-d)}{Dd}$
Mils	$1.41\times10^{-15}\frac{Dd}{(D-d)}$	$1.41\times10^{-9}\frac{Dd}{(D-d)}$	$1.41\times10^{-3}\frac{Dd}{(D-d)}$	$1.60\times10^{-3}\frac{Dd}{(D-d)}$	$62.6\frac{(D-d)}{Dd}$

*See Figure 4.

Table IV. Geometric Conductance and Resistance for Any Electrode System Where the Geometric Capacitance Is Known

For C_o Expressed in	Conductance (Mhos) G_o	Resistance (Ohms) R_o
Farads	$1.13\times10^{12}C_o$	$\frac{8.85\times10^{-14}}{C_o}$
Microfarads	$1.13\times10^{6}C_o$	$\frac{8.85\times10^{-8}}{C_o}$
Micromicrofarads	$1.13C_o$	$\frac{8.85\times10^{-2}}{C_o}$

Power factor

$$\Delta=\frac{I_g}{I} \quad (24)$$

$$=\sin\left(\tan^{-1}\frac{\epsilon''}{\epsilon'}\right) \quad (25)$$

$$=\sin\left(\tan^{-1}\frac{I_g}{I_c}\right) \quad (26)$$

$$=\sin\left(\tan^{-1}\frac{G}{2\pi fC}\right) \quad (27)$$

$$\simeq\frac{G}{2\pi fC}\ (\text{for } \tan\delta<0.1) \quad (28)$$

Dissipation factor

$$D=\tan\delta \quad (29)$$

$$=\frac{G}{2\pi fC}=\frac{I_g}{I_c} \quad (30)$$

$$=\frac{P}{I_cE} \quad (31)$$

$$=\frac{P}{2\pi fCE^2}=\frac{P_s}{2\pi f\epsilon'} \quad (32)$$

$$=\frac{\epsilon''}{\epsilon'} \quad (33)$$

$$=\frac{1.8\cdot10^{12}}{f}\cdot\frac{\lambda}{\epsilon'} \quad (34)$$

Loss factor

$$\epsilon''=\epsilon'\tan\delta \quad (35)$$

$$=\epsilon'\frac{G}{2\pi fC} \quad (36)$$

$$=\frac{G}{2\pi fC_o} \quad (37)$$

$$=\frac{1}{2\pi fC_o}\cdot\frac{1}{R} \quad (38)$$

$$=\frac{1.8\cdot10^{12}}{f}\cdot\lambda \quad (39)$$

$$=\frac{1.8\cdot10^{12}}{f}\cdot\frac{1}{\rho} \quad (40)$$

Current

$$I=\sqrt{I_g^2+I_c^2} \quad (41)$$

$$=E\cdot\sqrt{G^2+(2\pi f)^2C^2} \quad (42)$$

$$=2\pi fC_oE\sqrt{(\epsilon'')^2+(\epsilon')^2} \quad (43)$$

$$=2\pi C_o\cdot E\sqrt{(1.8\cdot10^{12})^2\lambda^2+f^2\epsilon'^2} \quad (44)$$

Specific current

$$i_s=2\pi\sqrt{(1.8\cdot10^{12})^2\lambda^2+f^2\epsilon'^2} \quad (45)$$

$$i_s=2\pi f\cdot\epsilon'\sqrt{\tan^2\delta+1} \quad (46)$$

(that is, current per unit volt per unit geometric capacitance)

Power loss

$$P=I_gE \quad (47)$$

$$=I_cE\tan\delta \quad (48)$$

$$=IE\cos\theta \quad (49)$$

$$=IE\sin\delta \quad (50)$$

$$=GE^2 \quad (51)$$

$$=2\pi fCE^2\tan\delta \quad (52)$$

$$=11.3\cdot10^{12}\cdot C_oE^2\lambda \quad (53)$$

$$=C_oE^2\cdot P_s \quad (54)$$

Specific loss

$$P_s=(11.3\cdot10^{12})\cdot\lambda \quad (55)$$

$$=2\pi f\epsilon'' \quad (56)$$

$$=2\pi f\epsilon'\tan\delta \quad (57)$$

(that is, loss per unit volt^2, per unit geometric capacitance)

USEFUL GEOMETRIC FACTORS FOR THE CALCULATION OF DIELECTRIC CHARACTERISTICS

1. Fundamental Relations. Specific inductive capacity (dielectric constant),

$$\epsilon'=\frac{C}{C_o} \quad (3)$$

where C = measured capacitance
and C_o = geometric capacitance (in the same units as C)

Specific conductance (insulation conductivity):

$$\lambda=\frac{G}{G_o}\text{ mhos per centimeter} \quad (58)$$

where G = measured conductance
G_o = geometric conductance (in same units as G)

Specific resistance (insulation resistivity):

$$\rho=\frac{R}{R_o}\text{ ohm-centimeters} \quad (59)$$

where R = measured resistance
R_o = geometric resistance (in same units as R)

The terms C_o, G_o, and R_o are thus analogous and may be denoted as dielectric *geometric factors*.

2. Tables of Geometric Factors. Tables I, II, and III give in a systematic manner the geometric factors relating to dielectric constant, conductivity, and resistivity for the three electrode systems, that is, *parallel plates*, *coaxial cylinders*, and *concentric spheres*.

In every case, the geometric factor, whether capacitance, conductance, or resistance, is given in erms of the practical electrical unit and the centimeter dimension. Hence, when the geometric conductance and resistance terms are used in equations 58 and 59 the resultant specific parameters will be in terms of mhos per centimeter and ohm-centimeters respectively.

Table IV is of great value for the determination of conductivity and resistivity when the electrode-system geometry is either unknown or too complex for calculation. In these cases, the conductance and resistance geometric factors may be determined from the tabulated equations if the geometric capacitance (C_o) of the electrode system is known or can be measured.

In the case of the parallel-plate and coaxial-cylinder electrode systems, they are assumed to be either "infinite" in extent or to be sufficiently defined by suitable guard electrodes.

All numeric constants appearing in the tables are given only to the third place.

Small A-C Generators and Their Applications

ARTHUR JAMES GIRDWOOD
ASSOCIATE AIEE

Too often an engineering "orphan," the small a-c generator, nevertheless, is important in its sphere. Factors related to the design and application of these units are discussed herein.

ALTHOUGH some attention has been given to manufacturing problems and to the production of compact units which could be put on the market as a standardized product in the interests of best economy, the small generator and its system too often has been an engineering orphan. Standardization is highly desirable and should be maintained wherever possible, but within the limit of best over-all economy to all concerned.

Until recent years there were relatively few sales of small a-c generating units in Canada. A series of events, however, has raised Canada's investment in these machines to impressive proportions. The first of these was the increase in the price of gold, a condition which resulted in the establishment of many small mining ventures beyond the reach of power systems. Then, Trans-Canada Airways, with its multitude of emergency landing fields, required many units. Modern warfare is power on wheels, and much of it is electric power dependent on small generating systems. Finally, industries, hospitals, and communications awoke to the necessity of stand-by power as an air-raid precaution.

Only the isolated single-generator system is considered in this article, as parallel operation in larger systems has received considerable attention elsewhere.

VOLTAGE-STABILITY PROBLEMS

The conditions giving rise to voltage-stability problems in small a-c generators may be divided into two general classifications, although these are not rigidly defined and verge into one another. Firstly, there is the problem of load changes, usually large and of comparatively long duration, of the order of one-half second and longer. This includes the starting of a-c motors and many types of welders. Sudden variations in the shaft load of motors already on the line should be considered also. Secondly, there is the problem of load pulsations, usually of smaller magnitude and of very short duration, of the order of $^1/_{20}$ or $^1/_{10}$ of a second. The pulsations may be caused by such loads as spot welders or a radiotelegraph key. These voltage changes may cause objectionable light flicker or a chirping noise in radio equipment.

A study of the voltage changes in small machines involves consideration of the voltage-regulator characteristics, the stator-winding resistance and inductance, the amortisseur-winding characteristics, the field characteristics, and the saturation of the a-c machine, as well as the stability or saturation of the exciter, its response rate, the regulator response, the stored kinetic energy in the rotating system, and the governor sensitivity, regulation, and response rate.

VOLTAGE REGULATORS

Over a period of years the vibrating-contact or Tirrell regulator was used so commonly that the word "Tirrell" became almost synonymous with voltage regulator. The maintenance cost for contacts was high. In small systems closely connected with radio equipment, the elimination of radio interference from the vibrating contact is difficult. To offset these difficulties the direct-acting rheostatic-type regulator was developed, where the voltage is distributed across numerous contacts in series connected across a resistance stack. Originally, these were slightly more sluggish than the Tirrell regulator because of static friction in the operating mechanism and the relatively high inertia of the armatures, although only rarely was this of any practical significance. However, modern regulators incorporate low-inertia armatures and frictionless spring mountings.

More recently there has been developed the exciter field-forcing-type regulator. These regulators effect a manifold increase in the exciter response rate by connecting to the exciter field a separate, controlled source of direct current which can be changed almost instantaneously. For example, if an exciter is operating at 60 volts, with 30 volts field *IR* drop, and the resistance of a rheostatic regulator is entirely cut out, 30 volts is available to operate against the inductance of the exciter field and to cause it to build up. A field-forcing-type regulator may raise the voltage on the exciter field to 250 volts, leaving 220 volts or an increase in rate of over seven times, to cause build-up. These regulators usually will impress a negative voltage, also, for building down. Armature-reaction-type generators, known as Amplidynes, have been developed, also, as small standardized motor generator sets for such service. These are rugged and provide the highest known ratio of amplification and power output for a given cost. Also, at extra cost, they may be used directly to excite the alternator.

Self-regulating generators, which are of two types, may be included here. Both actually tend to maintain constant flux rather than constant voltage, so that voltage varies at least as much as speed. In the first type the a-c flux is made to operate on the exciter flux in such a

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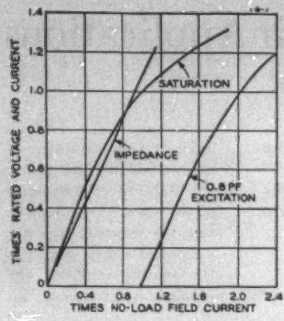

Figure 1. Typical saturation, impedance, and load excitation characteristics of a standard small a-c generator

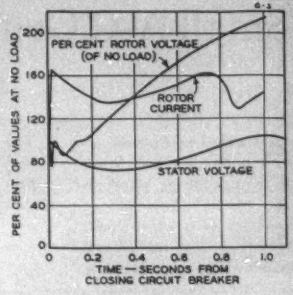
PER CENT OF VALUES AT NO LOAD
PER CENT ROTOR VOLTAGE (OF NO LOAD)
ROTOR CURRENT
STATOR VOLTAGE
TIME — SECONDS FROM CLOSING CIRCUIT BREAKER

Figure 2. Voltage and current variations during the starting of an induction motor when connected directly to a generator with a resistance-type direct-acting regulator

Motor inrush current at 600 volts—41 amperes (130 per cent of generator rating)
Generator: 31 kva; 0.8 power factor; 1,800 rpm; 600 volts
Exciter: 1 kw; 1,800 rpm; 125 volts

way as to reduce it; this is achieved usually by using a revolving-armature a-c generator and extending some turns of the exciter-armature winding into the main generator armature. The operation is almost exactly the same as that of a standard machine with regulator except that the amplification factor of the regulator is lost. Sensitivity must be achieved by operating with a small degree of saturation in both main generator and exciter. Comparatively small voltages are available to overcome the inductance of the exciter field, so that when heavy loads are thrown off and on, voltage swings are apt to be severe and of long duration, although the settled voltage regulation may be very close. Such machines have found wide application for almost purely lighting loads on ranches, summer resorts, and exploration camp sites.

The second type is the so-called saturated-pole machine. In this type, the main generator is operated well up on its saturation curve. The proportions are changed from the standard type of machine so that flux densities in the armature teeth, where a large portion of the core loss occurs, are kept low. A reasonable degree of saturation should exist, also, in the exciter, so that its voltage will not collapse with reduction in speed in the prime mover. Such machines have, of course, a greater settled regulation than the former type, the usual guarantee being eight per cent. However, it should be remembered that for a given load the transient swing will lie inside the settled voltage limit, a factor of considerable importance in many applications. This desirable feature of low voltage-transient swings has made it advisable in some cases to apply saturated-pole machine with more or less standard exciters and voltage regulators. Sometimes, such an arrangement is an alternative to the use of a standard machine with a field-forcing-type regulator; the preference is usually based on economic reasons.

Figure 1 shows a saturation and impedance curve of a more or less standard machine. Figure 2 shows the variations in rotor current, rotor voltage, and armature voltage, with the machine under the control of a resistance-type direct-acting regulator, when an induction motor with an inrush 130 per cent of the generator rating is thrown on the line. The regulator used was not modern, and some slight delay occurred before the exciter voltage began to build up.

Figure 3 shows the variation in generator output voltage of a machine under the control of an Amplidyne regulator. In this case, the speed of the machine was 1,200 rpm rather than 1,800 rpm, and its reactance was somewhat greater. The load thrown on was approximately rated load. It may be noted that the amount of voltage swing is less, but even more noteworthy is the short lapse of time until the voltage returns to normal—an interval so short as to be imperceptible for most applications. It is said that this performance can be improved.

Figure 4 shows the saturation and impedance curves of a particular saturated-pole machine, and Figure 5 the performance when the load is suddenly increased from half to full load. The time interval of return to normal is relatively long, but the amount of deviation is small. This arrangement finds particular application where part of the load is radiotelephone or telegraph equipment. The chirping noise is a function of the rate of change of voltage, and it may be noted that the rate

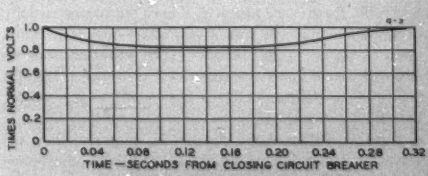

Figure 3. Output-voltage variation of standard a-c generator with Amplidyne regulator

Generator: 37.5 kva; 1,200 rpm
Load: 100 per cent rated load; 0.4 power factor

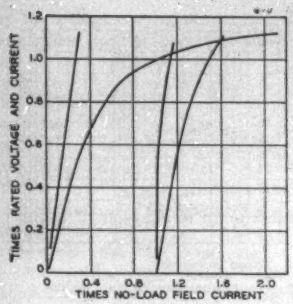

Figure 4. Typical saturation, impedance, and load excitation characteristics of saturated-pole small a-c generators

Figure 6. Calculated curves of terminal voltage of standard 63-kva a-c generators with direct-connected exciters when load is applied

Balanced three-phase zero-power-factor linear-impedance load equal to 75 per cent of the kva rating of the machine switched on; no original load
High-speed resistance-type direct-acting regulator
Constant rotational speed

A—3,600 rpm; 2 poles C—1,200 rpm; 6 poles E—720 rpm; 10 poles
B—1,800 rpm; 4 poles D—900 rpm; 8 poles F—600 rpm; 12 poles

of change here is least. It must be remembered, however, that the usual requirement that the machine operate satisfactorily at ten per cent overvoltage and undervoltage must be foregone, and that the speed regulation of the prime mover must be within reasonable limits. The Amplidyne, and similar regulators with standard machines, will maintain voltage over a fairly wide speed range and will operate at overvoltage and undervoltage.

SPEED OF ROTATION

This article makes no effort to discuss the relative merits and economics of low- versus high-speed internal-combustion engines. However, the author believes that, even if one does concede the low-speed engine longer life and less vibration, there still have been many cases where unnecessarily low speeds have been used for stand-by service. Figure 6 shows the voltage deviation of a-c generators of various rotational speeds, when reactive loads of 75 per cent of the rating of the generators are applied. It may be seen that the mo nentary voltage dip of the high-speed generator is much less than that of the low-speed generator. This divergence in characteristics increases greatly as the kva rating of the generator decreases.

Figure 7 shows the variation in cost with speed, on a unit basis, of gasoline-engine-driven sets. The dashed line shows the relative cost of a 50-kw unit designed so that voltage will not fall below 70 per cent when an inductive load of 200 per cent of the rating of the generator is applied. The purchase of machines having unnecessarily low speeds of rotation can be seen to constitute a waste of vital war material and labor of a serious nature. Also, it should be noted here that the saturated-pole-type machine is economical only at reasonably high speeds—not less than 900 rpm at 94 kva and not less than 1,200 rpm at 12½ kva.

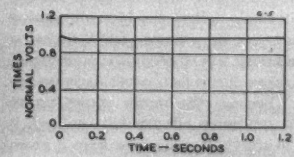

Figure 5. Output-voltage variation of saturated-pole small a-c generator with direct-acting rheostatic - type regulator

Generator: 31 kva; 1,200 rpm
Load: 100 per cent rated load; 0.4 power factor

PRIME MOVER

The necessity for close speed regulation readily can be understood. Figure 8 illustrates how reduction in speed can cause complete collapse of exciter voltage. Any reduction in speed reduces the exciter response rate and its ceiling voltage.

Low-speed engines are equipped with large flywheels. High-speed internal-combustion engines do not require large flywheels, and the ratio of stored kinetic energy to rated power energy per second will probably be about 0.7 or 0.8 to 1. This low kinetic energy can be compensated by a rapid-response governor. One manufacturer, at least, claims full stroke in 0.02 second. An average rate probably would be start of stroke in 0.1 second, full stroke, 0.5 second. If full kilowatt load is thrown on a machine having a governor with these characteristics and a stored-kinetic-energy ratio of 0.8, the speed will fall for a transient period to an 80 per cent minimum.

The effect of temporary overload is more serious. Most internal-combustion engines have a rapidly drop-

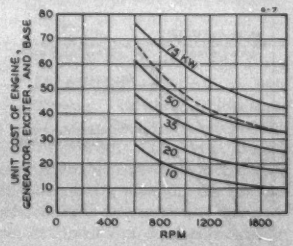

Figure 7. Approximate variation in cost with speed of gasoline - engine-driven a-c generator sets

Standard 0.8-power-factor generators rated for 50 degrees centigrade rise
Dashed line indicates a 50-kw machine designed so that starting an induction motor with inrush 200 per cent of the generator rating will not cause terminal voltage to drop below 70 per cent

ping speed-torque curve at open throttle when the torque demand exceeds the rating. Fortunately, heavy overloads are usually largely reactive, and it is seldom that the kilowatt demand exceeds the rating.

LOAD

Tolerance of voltage variation differs considerably. Figure 9 shows the approximate amount of voltage variation giving objectionable lamp flicker. Sometimes it may be more economical to provide a small separate source for lighting than to design the main supply to avoid lamp flicker.

Spot-welding equipment requires fairly close voltage regulation to avoid spoiled welds. It is common to specify that voltage remain within plus or minus five per cent of normal. If more than one welder is used on a single generator in addition to the load cycle and characteristics of each welder, the permissible number of spoiled welds should be considered. In the case of a welder which is on 1/20th of the total time and there are five welders on a single machine, if four welders operating at once give good welds and five at once give spoiled welds, one in $20^5/5$ or one in 640,000 welds will be spoiled. It is seldom that this will justify a 25 per cent increase in capacity.

Undervoltage releases and a-c magnetic contactors on a-c motor starters usually may be adjusted to remain closed at a voltage as low as 50 per cent of rated voltage. However, they may require as much as 85 per cent of rated voltage to close, if the starting operation should require any contactor to close during the voltage dip. Any induction motors already on the line and carrying load will draw an increased current when the voltage is lowered, and may possibly stall if the voltage drops to 70 per cent.

Within these limitations it is necessary to have sufficient voltage at the motor to start it. Load starting-torque requirements vary from that just sufficient to overcome static friction to 175 or 200 per cent of rated torque for some applications under adverse conditions.

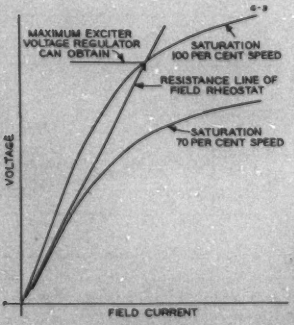
MAXIMUM EXCITER VOLTAGE REGULATOR CAN OBTAIN
SATURATION 100 PER CENT SPEED
RESISTANCE LINE OF FIELD RHEOSTAT
SATURATION 70 PER CENT SPEED
VOLTAGE
FIELD CURRENT

Figure 8. Diagram illustrating how reduction in speed of the prime mover can cause exciter voltage to collapse

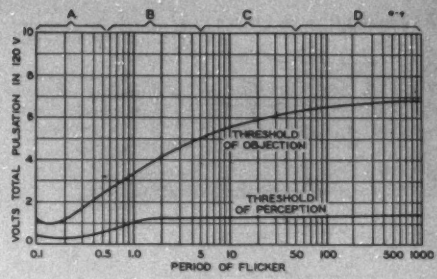

Figure 9. Voltage pulsations causing lamp flicker

A—Cyclic pulsations
Reciprocating pumps
Compressors
Automatic spot welders

B—Low-frequency cyclic pulsations
Flashing signs
Arc welders
Manual spot welders
Drop hammers
Planers, saws, shears
Group elevators

C—Frequent noncyclic pulsations
Single elevators
Hoists, cranes
Wye-delta change on elevator motor-driven sets
X-ray equipment

D—Infrequent noncyclic pulsations
House pumps
Sump pumps
Air-conditioning equipment
Theatrical lighting
Domestic refrigerators
Oil burners

Starting torques developed by motors also vary with the type of motor as well as with the size and speed. Considering the load torque required as TL, and the full-voltage starting torque of the motor as TM, then $\sqrt{TL/TM}$ of full voltage will be required at the motor for a successful start. This determines the lowest voltage tap that may be used on a reduced-voltage or series-impedance-type starter, if the generator and exciter, under regulator control, is capable of returning to full voltage after the initial dip, carrying the inrush obtained. If it is not, the highest voltage to which it will return should be used in determining the tap. This calculation is one of trial and error, as the higher the tap, the higher the inrush and, therefore, the greater the voltage dip. When a proper solution has been reached, however, an estimate of the bottom of the voltage dip before recovery occurs should be made to see if it runs afoul of any previous limitations.

If the load to be started has low inertia, the motor may start and come sufficiently far up to speed that the motor current will have fallen considerably during transient conditions before the voltage reaches its lowest point. If the conditions are thoroughly understood, advantage may be taken of this fact, particularly on unregulated systems. Because the motor comes up to speed faster and the saturation effect is fully utilized, it is usually possible to start a larger motor from a given generating system on full voltage than on reduced voltage if the voltage dip is not objectionable.

The presence of other load or control devices may necessitate use of special starting equipment. The wound-rotor induction motor provides the best conditions, and by insertion of sufficient secondary resistance, almost ideal conditions may be obtained. It should be remembered, however, that the value of external resistance that gives the highest starting torque does not give the lowest inrush. When, therefore, a wound-rotor motor is used because of limited generating equipment rather than for speed control or for starting torque, as is usual, it is essential that the design of the generator, motor, and control be co-ordinated.

A compensator-type reduced-voltage starter with a squirrel-cage induction motor introduces a reactive magnetizing current of the order of 10 to 25 per cent of the starter rating in addition to the necessary inrush to the machine. Except for this addition, the inrush current is reduced in the same proportion as the torque. Thus, if the available starting torque of the motor is 150 per cent, if the inrush is 500 per cent at full voltage, and the load requires 50 per cent torque, the motor may be connected to a 60 per cent tap. Torque developed will be $(0.6)^2 \times 150 = 54$ per cent. Inrush will be $(0.6)^2 \times 500 + 25 = 180 + 25 = 205$ per cent of the motor's normal current.

Series resistance or reactance starters are commonly used. Often, while they can be used to advantage, it is only at a considerably reduced ratio of motor rating to generator rating. For example, a series resistor used to reduce the starting torque to the minimum permissible 50 per cent, would reduce the inrush to 290 per cent. As the resistor is a unity-power-factor device, the reactive current actually will be less than with a reduced-voltage starter by the amount of the magnetizing current of the autotransformer. The much higher in-phase current will have some effect, of course, but actually a motor started with a resistor will have very little more effect on the generator voltage, in most cases, than one with a reduced-voltage starter, provided there is no change in engine speed.

In the aforementioned example, a motor started by a compensator-type reduced-voltage starter would put a load on the engine of about 75 per cent or less of the rating of the motor to get a torque output of 50 per cent. A combined motor and resistor starter for the same starting torque would put a load on the engine around 270 per cent of the motor rating. It may be necessary, therefore, that the WR^2, or governor response, and the open-throttle speed–torque characteristics of the engine be co-ordinated to carry a considerable overload during the starting period of the motor.

With a series reactance starter, no extra load is placed on the engine above that obtained with a reduced-voltage starter. The reactive current is greater, however. In the example given, with a reduced-voltage starter there would be a reactive current of about 190 per cent of the rating of the motor, whereas with a reactor starter the reactive current would be about 280 per cent.

If either of these systems is feasible, the choice between the two will depend largely on generator and engine characteristics. In general, the reactor starter would be better on a high-speed machine where the transient reactance of the generator would probably be low and the stored kinetic energy of the engine would be low also. On relatively slower units probably a resistor starter would be better.

In extreme cases more expensive arrangements can be made. When the conditions are known, the motor manufacturer may be able to offer a machine having a somewhat higher ratio of starting torque to inrush than the best standard units. In such a case it is not advisable to ask for competitive estimates on low inrush, as this may result in sacrifice of more important characteristics. For example, a given rating may have an AIEE standard efficiency of 89 per cent. The manufacturer's regular line may average 90.5 per cent. If forced to give a competitive estimate on low inrush, he may decide to lower his efficiency margin. In some locations where fuel is expensive, the loss of one per cent efficiency on a 50-horsepower motor may cause a loss of approximately $100 a year which might have been avoided if the manufacturer had been asked merely to offer an effective solution to the whole problem.

Starters incorporating power-factor correcting devices such as capacitors in series or parallel have been proposed but I do not believe have been used to date. It is seldom that a cheaper satisfactory method cannot be found. However, they can be developed in case of necessity.

Series capacitors have been proposed to offset machine reactance for spot welding and similar duty. It would be necessary to protect against excessive overvoltages across the capacitor during short circuits or heavy overloads. So far the use of special-design overside generators has proved more economical.

LOAD PULSATIONS OF VERY SHORT DURATION

From the foregoing discussion it can be understood that when the load pulsation is of very short duration, in the order of two to eight or ten cycles per second, the best that any governor or voltage regulator could do is to maintain average speed and voltage. No one seems to expect that rapid pulsations in speed can be prevented by means of a governor. However, it does seem to be expected that rapid regulating systems can prevent voltage flicker of similar duration. This is true in spite of the fact that, in general, an internal-combustion engine will respond almost immediately after the throttle has been opened, whereas a definite time interval is necessary to build up the main flux linkage of the generator sufficiently to overcome even the transient reactance drop.

Assuming constant speed, therefore, it is necessary that the reactances be kept low enough to limit the voltage variation to the required amount, as practically no help

can be expected from any regulating system. In fact, a regulating system having some lag is preferable as it would act only to correct average voltage. A fast regulator, on the other hand, by causing the exciter voltage to rise during load periods and therefore to be higher when the load is dropped and vice versa, is very apt to increase rather than reduce voltage variations. In other words, conditions may approach that shown in the lower part of Figure 10.

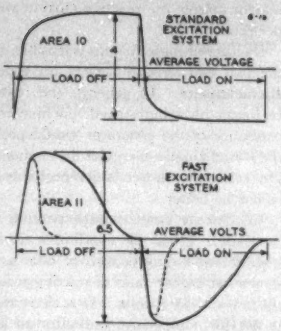

Figure 10. Possible effect of keyed load on voltage of small a-c generators

Slower regulation gives the effect, shown in the upper half of Figure 10, of having a considerably smaller voltage deviation from the average. A much faster excitation system might give the condition shown by the dotted line, but for many purposes even that will not be as satisfactory as the top half of the figure.

The purchaser of small generating equipment should consider carefully his reasons for specifying certain limits to voltage variation of short time duration. Naturally, the determination of these limits rests only with the user or manufacturer of the load equipment. The psychological factors of lamp flicker have been shown already. This is the most common limitation. Use of the curves should be made with judgment dependent on class of service as well as the duration and frequency of periods of disturbance. The limitation of five per cent high to five per cent low commonly required for spot-welding equipment has also been noted. Correct voltage is essential to the efficiency and life of resistance devices, and for emission of energy in one form or another. Where the voltage pulsation is fairly rapid, however, its effect may not be as severe as would be expected. For example, if t is the heating time constant of a resistance element, that is, the time to reach $(1-1/\epsilon)$ or 63.1 per cent of its final value, $K\!E$ the overall voltage variation, and f the frequency of a complete cycle of variation in cycles per second, then the variation in temperature rise over the ambient will be

$$\frac{(1+k)^2-1}{1+(2\pi ft)^2}$$

If for example, $K=0.05$, $f=10$, and $t=0.5$, temperature variation $=\dfrac{0.10}{1+31.4^2}=0.0032$, or about $^3/_{10}$ of one per cent. However, limitations other than actual temperature change may often appear, and as has been said, the type and degree of limitation can be determined only by the user or manufacturer of the load equipment.

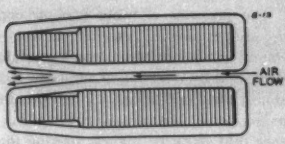

Figure 12. Tapered pole construction for small a-c generators showing divergent nozzle effect of the air path through the interpolar space

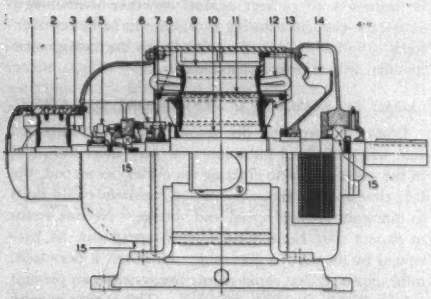

Figure 11. Cross section of a typical synchronous machine of antifriction-bearing type with direct-connected exciter

1—Exciter field coil
2—Exciter pole piece
3—Exciter armature coil
4—Exciter commutator
5—Brush yoke assembly
6—Brush holder stud
7—Collector rings
8—Starting winding
9—Stator punchings
10—Rotor-spider
11—Field-pole punchings
12—Stator coil
13—Field-coil winding
14—Fan
15—Bearing

CONSTRUCTION AND DESIGN

The problem of arrangement of the parts of the small machine is largely one of economics, and differs with almost every manufacturer. The designer must lay out his machine in such a way as to utilize his previously accumulated experience and data. Above all else, he must rely largely on his existing machine tool, die, and pattern equipment.

A typical design is shown in Figure 11. The main feature is the use of revolving-field machines down to 6.3 kva at 1,800 rpm. The rotor-spider punchings are piled individually or in groups on the shaft with a press fit by means of a small press, and are keyed to it. The poles are retained by means of dovetails and keys. The pole insulating collars are usually cloth-base bakelite bonded. The coils are insulated from the pole body by means of high-temperature varnished cambric. The field-coil conductor is usually round copper Formex insulated to provide high dielectric strength at crossovers, high abrasion resistance, uniformity, good space factor, and good heat transfer. Bonding of the coil is accom-

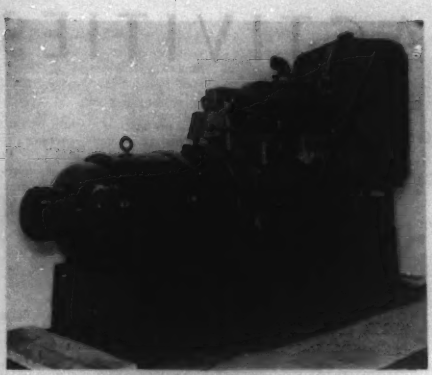

Figure 13. Typical gasoline-engine-driven generator set

Generator: 63 kva; 0.8 power factor; 1,200 rpm; 550 volts; three phase; 60 cycles

Engine: 135 horsepower

plished by means of high-temperature low-solvent varnish, and the coil is baked under pressure for approximately 24 hours. Stator cores and frames are similar to standard induction motors. Collector rings are pressed onto cloth-base bakelite shells mounted on the shaft.

Up to sizes of the order of 300 kva at 1,200 rpm, these machines are single-end ventilated. This is so because the main limitation on the design of these machines is field-coil heating. Single-end ventilation cools the field coils more effectively and at the same time offers an opportunity to save material, weight, and space. By arranging the mounting, ventilation of the exciter and further economy of weight and space can be effected.

The collector-end end shield contains a barrier wall mounting the bearing. The exciter is mounted directly on the shield with the commutator next to the bearing. The exciter brush-holder yoke is mounted on the bearing cap. Ventilating air enters at the bottom of the shield beyond the barrier, and must pass up and over to enter the machine. The commutator and end portions of the machine are thus situated in a transverse stream of cooling air—the most effective means of cooling this type of machine yet discovered. While some air is allowed to pass outside the core between the core and the frame, the main body of ventilating air is directed through the *bore*, along the air gap, and between the field poles. Air also enters the outside end of the exciter, cooling the field coils. The upper part of the shield is removable, giving ready access to all brushes.

As mentioned before, field-coil cooling constitutes the main limitation to the design of a small compact unit. It is desirable, therefore, that the sides of the adjacent field coils should be reasonably parallel and fairly close together, as this is the best condition for heat transfer. An axial component of air velocity of 4,000 to 6,000 feet

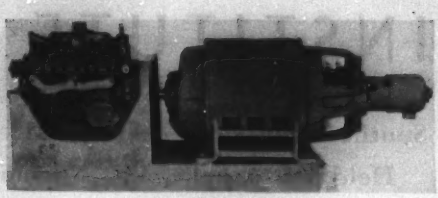

Figure 14. Two-pole generator directly connected to a Ford V-8 engine

Generator: 75 kva; 0.8 power factor; 3,600 rpm; 440 volts

a minute between the poles is desirable both for effective heat transfer and to prevent the accumulation of dirt at this point. This represents a velocity head of between 1 and $2^1/_4$ inches of water. Very often this pressure head is not available in the fan, so it is essential that some of the velocity head be recovered.

Figure 12 shows how a divergent nozzle can recover a large part of the velocity head if the angle of divergence lies within fairly narrow limits, such as 10 to 15 degrees. The device is applicable in the field coils of a machine. A number of punchings at the fan or exhaust end are trimmed to a narrower width of pole body than the remainder. The field coil, when wound on a pole so constructed, forms an excellent divergent nozzle. It remains, then, to calculate the pressure drop in the system for an assumed air flow and then, based on the law that total pressure drop varies with the square of the air flow, to plot volume against pressure on the fan-characteristic curve sheet.

Once this figure is known, the scrubbing velocity of the air against various parts of the field structure can be estimated. The fact that the air in the gap has a rotational component relative to the pole face because of the drag of the stator bore should be noted.

The heat transfer from the various parts can be estimated next. As radiation is of the order of 0.004 watt per square inch per degree centigrade, its heat loss from any part not subjected to the air flow can be ignored safely. A heat-transfer circuit then can be set up. The addition of the air-temperature rise and an allowance for drop through the coil itself gives the field-temperature rise. In the instance illustrated, calculated rise was 49 degrees centigrade and the test rise was 52 degrees.

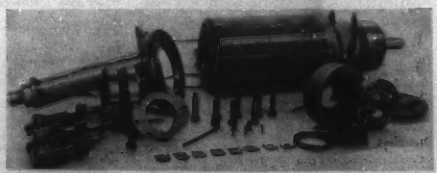

Figure 15. Rotor parts for the two-pole generator shown in Figure 14

INSTITUTE ACTIVITIES

Southern District Technical Meeting to Be Held at Roanoke, Va., November 16–18

A three-day technical meeting of the AIEE Southern District will be held in Roanoke, Va., November 16–18, 1943. The tentative technical program has been arranged to be of aid in the war effort. The four technical sessions tentatively scheduled deal with the following subjects: wartime operation, wartime development, special equipment, and power supply. In addition, there will be a general session opening the meeting on November 16, and two dinner meetings with specially invited guest speakers. A meeting of the District executive committee will be held at the conclusion of the opening session. Headquarters for the District meeting will be in the Hotel Roanoke.

REGISTRATION

Members who receive an advance registration card by mail should fill in and return the card promptly. This will save time on arrival at the meeting, as badges for advance registrants then can be prepared in advance. No registration fee will be charged for members, enrolled students, and the immediate families of members. There will be a $2.00 registration fee for all other nonmembers.

COMMITTEES

Those making arrangements for the meeting and the chairmen of subcommittees are: A. P. Gompf, *chairman;* E. S. Fitz, *vice-chairman;* W. I. Whitefield, *hotels and transportation;* Cecil Gray, *publicity and attendance;* R. C. Bailey, *technical papers;* Claudius Lee, *student activities;* C. L. Crosby, *finance.*

Tentative Technical Program

Tuesday, November 16

9:00 a.m. Registration

10:30 a.m. Opening Session

A. P. Gompf, presiding

Welcome: **Honorable Walter W. Wood**, mayor of Roanoke, Va.

Response: **C. W. Ricker**, vice-president, Southern District, AIEE

Address: **N. E. Funk**, president, AIEE

10:30 a.m. District Executive Committee Meeting

1:00 p.m. Executive Committee Luncheon

2:00 p.m. Wartime Operation

H. B. Wolf, presiding

DP.* The Effect of Kilovar Supply on Design of Systems for Load Growth. **T. W. Schroeder, J. W. Butler,** and **N. H. Meyers,** General Electric Company

DP.* The 13,500-Kva Static Capacitor Installation at Newport News. **E. L. Harder,** Westinghouse Electric and Manufacturing Company, and **V. R. Farrack,** Virginia Public Service Company

DP.* Capacitor Application in Pipe-Line Pumping Stations. **M. A. Hyde, Jr.,** Westinghouse Electric and Manufacturing Company

7:30 p.m. Dinner Meeting (Informal)

J. H. Berry, presiding

Guest speaker: Representative from Headquarters of the U. S. Armed Forces

Wednesday, November 17

9:30 a.m. Wartime Development

Stanley Warth, presiding

DP.* Growth of the Higgins Plant. **Milton L. Levy,** Higgins Industry, Inc.

DP.* High-Voltage Low-Pressure Gas-Filled Cable (illustrated by motion pictures). **W. A. Del Mar** and **A. F. Gambolia,** Phelps Dodge Copper Products Corporation, and **W. F. Nimmo,** Virginia Electric and Power Company

DP.* Training Program for Future Technicians. **Dean W. S. Rodman,** University of Virginia

2:00 p.m. Special Equipment

J. E. Housley, presiding

DP.* Modern Hydraulic Turbine Governor Design and Operating Characteristics. **C. L. Avery,** Woodward Governor Company

The above paper will be discussed by **C. L. Karr,** Tennessee Valley Authority

DP.* Design and Operation of Governor Control for Hydro Units. **J. F. Roberts,** Allis-Chalmers Manufacturing Company

C. P. Almon, Jr., Tennessee Valley Authority, will discuss the paper by J. F. Roberts

DP.* Design of Tie-Line Control Equipment. **S. B. Morehouse,** Leeds and Northrup Company

The above papers to be discussed by **J. T. Logan,** Georgia Power Company, and **A. J. Skaale,** Carolina Power and Light Company

DP.* Influence of New Material on Future Design. **R. C. Bergvall,** Westinghouse Electric and Manufacturing Company

2:00 p.m. Student Conference

Claudius Lee, presiding

7:30 p.m. Dinner Meeting (Informal)

E. W. O'Brien, presiding

Guest speaker: **E. H. Alexander,** General Electric Company, on "Electronics in Industry," followed by movie film

Thursday, November 18

9:30 a.m. Power Supply

A. S. Hoefflin, presiding

DP.* New Chesterfield Station. **C. C. Dodge,** Stone and Webster Engineering Corporation

DP.* Additional Power Supply, Hampton and Alexandria Stations. **G. M. Tatum,** Virginia Public Service Company, and **R. H. Boaz,** Gilbert Associates, Inc.

DP.* The Paddy's Run Power Station of the Louisville Gas and Electric System. **M. S. Winstandley,** Louisville Gas and Electric Company

*DP: District paper; no advance copies are available; not intended for publication in *Transactions.*

AIEE Employee Pension Plan Adopted by Board of Directors

A retirement system, which will provide a pension for all AIEE employees who reach 65 years of age after having completed at least 12 years of service, was adopted by the Institute's board of directors on August 4, 1943 (*EE, Sept. '43, p. 412*). The system also provides for disability income for employees who are at least 50 years old and who have completed 20 years of service in the Institute. Participation is optional for present employees of the Institute, but will be a condition of employment for all future employees. All present employees who choose to participate immediately will be entitled to a prior-service credit which will increase their benefits without any additional contribution on their part. Participation will be automatically terminated with termination of employment.

A retired employee will receive an annual income amounting to $1^1/_2$ per cent of average annual salary multiplied by the number of years of his service subsequent to establishment of the plan. Prior-service credit will entitle present employees who join the system to an additional pension amounting to a percentage (determined by the number of years of prior service) of the highest earned salary. Minimum retirement income will be $600 per year and the maximum $3,000 per year.

The system will be financed by joint contributions from the Institute and the employees. For the latter the contribution will be $4^1/_2$ per cent of earned salary. In addition, the Institute will deposit a preliminary lump sum to cover payments for service prior to the establishment of the system. If all present employees join the retirement system this will amount to $88,000.

Any compulsory contributions, premiums, or taxes, required from the employer by future insurance, workmen's compensation, or similar legislation will be met by

reduction in the benefits payable under the system. Contributions of both employer and employees may be reduced to compensate for any payments required by such laws, or the board of trustees may arrange for such payments to be made from the retirement fund.

Administration of the system will be by a board of three trustees: a member of the board of directors, will represent that body; the second must be a Fellow of the Institute who is not a member of the board of directors; and the third will represent the employees. Members of the first board of trustees are: Past-President H. S. Osborne, representing the board of directors; H. H. Barnes (F '13); and National Secretary H. H. Henline, representing the employees.

National Technical Meeting Held in Salt Lake City, Utah, September 2–4

Five technical sessions and five technical conferences were held during the national technical meeting at Salt Lake City, Utah, September 2–4, 1943. The session on electrical equipment for military aircraft and the conferences on metallurgy and mining were principally related to the war effort. Approximately 200 persons attended the three-day meeting, which had headquarters in the Hotel Utah.

The meeting was opened by A. LeRoy Taylor (F '41), general chairman of the meeting committee. After a few words of greeting, he introduced the Honorable Herbert B. Maw, governor of Utah, who gave the official address of welcome.

President N. E. Funk also was introduced, and spoke briefly. He expressed the opinion that, as the sessions continued, members would find them well worth the time and effort. In the past some members had advocated curtailment of meetings, but in view of changing world conditions and the fact that so many members now find themselves in different kinds of work, Doctor Funk stated that more than ever the meetings serve as a valuable medium for the exchange of information.

At the conclusion of the opening meeting, a technical session on theory and machinery was held, with B. C. J. Wheatlake (A '16), manager of General Electric Company, Salt Lake City, presiding. Four technical papers were presented.

BUREAU OF MINES INSPECTION

In the afternoon of the opening day, the laboratories of the United States Bureau of Mines were inspected, where the microscopic and spectroscopic analyses of ore are made. In the chemistry laboratory the sonic flocculation of smoke was demonstrated, and in the mechanical laboratory demonstrations of tensile tests and torsional fatigue were seen.

ULTRAHIGH-FREQUENCY DEMONSTRATION

After the visit to the United States Bureau of Mines, the campus of the University of Utah was visited, and in the chemistry laboratory an ultrahigh-frequency demonstration was given by the students under the direction of Professors O. C. Haycock and L. D. Harris. The transmitter used was designed for a ten-centimeter wave, operating at 3,000,000,000 cycles per second. For laboratory work the importance of selecting a wave length small enough to be used with the apparatus was emphasized. By means of a radiation horn transmitter and parabolic receiver, two students with their backs to the audience, by turning both transmitter and receiver in synchronism, were able to pick up the location of a third student with a piece of copper screening at several different locations in the rear of the audience. It was also demonstrated how two specially designed transmitters, each using a different frequency note, could be used for the blind landing of airplanes. Questions were answered by Professors Harris and Haycock.

CONFERENCE ON ELECTRONICS AND COMMUNICATION

The conference on electronics and communication was held Thursday evening, with Professor A. L. Albert (F '41), electrical-engineering department, Purdue University, presiding. Preceding the presentation of scheduled conference papers, President Funk was introduced. He gave an interesting historical summary of the development of electricity from the time of its discovery to the present, showing how slow early progress was and how rapidly developments have progressed in the last few decades. In concluding he said that no one should worry about the new frontiers or possibilities after the war, but, instead, everyone should devote the utmost energy toward his work.

An address "Electronics—A Tool for Industry" was delivered by R. H. Rogers of the General Electric Company, Salt Lake City, and illustrated with lantern slides. Mr. Rogers described the fundamental characteristics of the five or six different kinds of electronic tubes and the fundamental circuits employed. He explained that $^1/_{25}$ to $^1/_{25}$ of a second is the time required for a magnetic contactor to operate, whereas an electronic contactor operates in $^1/_{10,000}$ of a second. The high speed of operation permits many valuable applications without wear and pitting of contacts, as in the printing of cement bags, where the paper is traveling at a rate of 600 feet per minute. Another interesting application is the automatic leveling of the platform of a large crane-type shovel by electronic means.

Following Mr. Rogers' address E. V. Potter explained several uses of electronics in metallurgical research.

Other conference presentations in this session applied to the field of communication. F. A. Cowan (M '29) transmission engineer with the American Telephone and Telegraph Company, New York, N. Y., L. N. Schindel (A '36), Mountain States Division, Denver, Colo., and J. E. Heller (M '38), Pacific Telephone and Telegraph Company, San Francisco, Calif., described the protective devices and circuit protection against lightning employed on a transcontinental toll cable. The effects of lightning are reduced by providing conductive paths surrounding the telephone plant with a sheath having good conduction; protectors bleed off overvoltages. Mr. Heller explained that lightning is not particularly severe in the Pacific Northwest but that nevertheless lightning-rod protection and ground rods had been installed. In conclusion he stated that five other important routes were available, assuring continuity of service.

After the presentations Professor Albert conducted a round-table conference on the methods of teaching communication and ultrahigh frequency. Most of the discussion considered whether highly specialized subjects should be taught or whether more time should be devoted to fundamentals. It was recognized that a thorough grounding in fundamentals is essential for the students, but it also was considered necessary to train them along specialized lines so that they might obtain employment in their respective localities after graduation. The importance of teaching English also was discussed.

CONFERENCE FOR STUDENTS, COUNSELORS, AND OFFICERS

Approximately 40 attended the luncheon conference for students, Branch counselors, and national officers, held Friday noon in

Analysis of Registration at 1943 Pacific Coast National Technical Meeting

Classification	District 9	District 8	District 10	Miscellaneous	Totals
Members	78	34		34	146
Men guests	17	4		13	34
Women guests	11	2			13
Totals	106	40	—	47	193

Registration at Pacific Coast Technical Meetings—1933–1943

Year	Location	Registration
1943	Salt Lake City, Utah	193
1942	Vancouver, B. C.	245
1941	Yellowstone Park	322
1940	Los Angeles, Calif.	465
1939	San Francisco, Calif.	*
1938	Portland, Ore.	454
1937	Spokane, Wash.	266
1936	Pasadena, Calif.	*
1935	Seattle, Wash.	269
1934	Salt Lake City, Utah	232
1933	(No Pacific Coast convention)	

* Combined with summer convention.

the Sea Gull Room of the Temple Square Hotel. President Funk addressed the luncheon and explained that he saw no reason to be disturbed about conditions in the postwar period, if engineers would devote all their energies to their work and show some degree of human intelligence. Laziness would prevent putting into effect their ideas as quickly as possible. To indicate the significance of existing developments, President Funk pointed out that during his early experience in the electrical industry the radio and telephone did not exist and the first electric lamps were just coming into being. He again brought to attention the rapid strides in recent years, and by way of illustration he cited that present developments in the ultra-high-frequency field would have been considered impossible 30 years ago. He said that in the next 50 years there would be no limit to the possibilities open to engineers.

National Secretary H. H. Henline, who was present at the first conference on student activities, held in Salt Lake City in 1926, addressed the luncheon meeting on the organization and work of the Student Branches. Organized to give the students opportunities to come into contact with older members of the Institute, the first Branch came into existence in 1902. Today the number of Branches totals 125. Mr. Henline further explained that the plan for organizing the Institute into Districts was put into effect in 1920, and he gave the date of establishment and the location of each Branch in the Pacific and Northwest Districts. In conclusion, he urged counselors and students to continue their activities as effectively as possible during present times, so as to be ready to resume normal activities after the war. He urged those who were able, to follow up Branch work by showing an interest in Section and national meeting activities.

Professor R. E. Lindblom (M '35) chairman of the committee on student activities in the Northwest District, presided over the meeting. Other speakers included Vice-President E. W. Schilling (M '33), Vice-President L. A. Bingham (M '39), and Professor F. W. Maxstadt (M '26) chairman of the committee on student activities in the Pacific District.

CONFERENCES ON METALLURGY AND MINING

These conferences were arranged as aids in the war effort to give engineers in general a better understanding of the problems involved in mining and metallurgy. The electrical industry is one of the largest users of copper, and a first-hand knowledge of the industry should aid in the conservation of this critical material. In the first conference, the physical aspects and the electrical properties of copper and copper alloys were described by P. H. Brace, Westinghouse Electric and Manufacturing Company. Metallurgical problems arising from the use of copper in electrical equipment were discussed in another paper prepared by E. R. Parker, General Electric Company, and presented by F. A. Compton, Jr. (A '39). "Metallurgy Production of Ferroalloys in Western States," "Production of Light Metals," and "Quantitative Spectrographic Analysis" were presented, respectively, by S. F. Ravitz, H. W. St. Clair, and G. W. Marks, of the United States Bureau of Mines, Salt Lake City. Vice-President E. W. Schilling presided.

In the conference on mining, held Saturday morning, and presided over by Doctor H. T. Plumb, technical-program chairman of the meeting committee, several conference papers were given. Historical and statistical data on copper mining throughout the world, as well as a description of the Open Pit Mine of the Utah Copper Company, Bingham, were presented by Robert S. Lewis, professor of mining at the University of Utah, Salt Lake City. The process of copper smelting at the Garfield plant of the American Smelting and Refining Company was described by W. G. Rouillard, superintendent of the Garfield smelter, and the uses of electricity in the mining and milling of copper were outlined by R. J. Corfield (M '41), electrical engineer, Utah Copper Company, Garfield.

In the afternoon a number of members went on the inspection trip to the Open Pit Mine at Bingham, where blasting operations were in progress. Operations at the pit were explained over a loud-speaker system to the party by Lewis Buckman, superintendent of mines, and R. J. Corfield.

ORGAN RECITAL

Friday noon a number of the members and guests attended a special organ recital in the Mormon Tabernacle, given by Alexander Schreiner, tabernacle organist, who illustrated the unusual features of the organ. The acoustic properties of the tabernacle were demonstrated also by the dropping of a pin, the sound of which could be heard distinctly at the far end of the structure.

Friday evening members and guests attended a get-together dinner at Maxfield Lodge in Big Cottonwood Canyon. After dinner an illustrated lecture, "Exploring Your Back Yard," was given by Professor R. E. Marsell of the department of geology, University of Utah. Professor Marsell's subject dealt with the geology of the Bonneville Basin from the early stages of "tillite," the deposit from an ancient glacier. He explained that originally the Bonneville Basin contained a fresh water lake approximately equal in area to that of Lake Michigan, which over hundreds of years has receded to the present Great Salt Lake, and which has retained the mineral deposits from the larger body of water.

Pamphlet on Emergency Rating of Power Cables Now Available

The nine conference papers on the emergency rating of power cables presented at the cable conference during the AIEE national technical meeting last January in New York, N. Y., have been assembled and reproduced in single pamphlet form for distribution. Copies of this pamphlet, AIEE Special Publication 6, may be obtained from Institute headquarters, 33 West 39th St., New York 18, N. Y., at 75 cents per copy. A 20 per cent discount will be allowed on orders of ten or more sent to one address at the same time.

These papers report that several of the country's largest power utilities have raised their normal operating temperature on power cables above industry standards after having conducted investigations on the deterioration of insulation, the mechanical effects of such increases, and recognition of an increase in the rate of cable failure. The general consensus of opinion is that it is safe to operate cables at emergency loadings equivalent to operating temperatures 10 to 20 degrees centigrade above present normal temperatures without shortening too greatly the life of the cable.

Brief abstracts of the papers follow.

Cable Application for Maximum Conservation; *G. L. Carlisle, War Production Board.* This paper sets forth the conditions under which the power branch of the War Production Board reviews applications for the purchase of power cables, and cites the factors which must be satisfied as to the ability of the utility to meet the situation before permission is granted to purchase.

Emergency Overloading Policies for Power Cables; *H. W. Collins (A '22), Detroit (Ill.) Edison Company.* This paper refers to a study made on the overloading of three-conductor, belted and shielded 24-kv paper cables in ducts as high as 140 to 150 degrees centigrade to meet the emergency ratings of transformers to which they were connected. Some of the cables failed near the end of the emergency load cycles, others appeared to be near failure, and the remainder not appreciably affected. There was no difference in results for new cables and some nearly 20 years old. It was finally decided to limit copper temperature to 110 degrees centigrade on the basis that emergency loading would not occur more often than once in every five years. If the frequency of emergency loading occurs as often as once a year, then the maximum emergency temperature allowable is 95 degrees centigrade. It is recognized that if the cable is to be operated at emergency loadings, adequate provision for expansion must be provided in the manhole design, and there is the possibility of split sheaths if these high loads are suddenly applied to new cable that has not been seasoned.

Cable Overloading, Its Effects and Possibilities as a Wartime Expedient; *H. L. Davis, Jr. (A '27) and C. S. Schifreen (A '26) special investigation section, Philadelphia (Pa.)*

Electric Company. Reasons for increasing the loading on a cable and what careful consideration must be given to the subject before executing it are discussed herein. An interesting report is given on the experiences of their company on increase of loading on 13-kv and 66-kv cable systems. On a group of 13-kv cables which carried emergency loads, the failure rate was nearly four times the rate prior to the time of overloading and about seven times the average for the entire system. Later, when this same group carried its normal load, the failure rate was nearly two and one half times that which it was originally and six times the average rate for the entire system. Examination of the failures indicated that they were mostly from lead sheath cracks which developed due to cable movement; about 40 per cent of the total number of lengths in the group had sheath defects. On the 66-kv system a comparison was made of the failure rate on a Group "C" with a Group "D." Group "C" operated with short-circuited sheaths and Group "D" with open-circuited sheaths. The conductor temperature on Group "C" was 69 degrees centigrade and sheath 55 degrees centigrade; on Group "D" 63 degrees centigrade and 50 degrees centigrade respectively. Originally when both groups were operated below AEIC temperature, that is 60 degrees centigrade, they had the same failure rate. When during 1930–1932 Group "C" was overloaded, its total trouble rate was seven and one half times that for Group "D" and two and one half times that for the system. Later when Group "C" was changed over to open-circuit operation the failure rate dropped to one fifth of that during 1930–1932 but remained three times that for Group "D." The major cause of failure was bursting of the lead sheaths from excessive internal pressure.

Practical Wartime Cable Operation; *G. E. Dean (A '28) Public Service Electric and Gas Company, Newark, N. J.* This company rates three-conductor belted 13-kv cables at 75 degrees centigrade for cables installed prior to 1920 and 80 degrees centigrade for cables installed since 1920. The AEIC value for temperature is 77 degrees centigrade for 26-kv belted cables; 57 degrees centigrade is used for cables installed prior to 1920, 62 degrees centigrade for 1920–1924 cables, and 67 degrees centigrade for cables installed since 1924. The AEIC value for temperature is 64 degrees centigrade. For 26-kv shielded cables, 75 degrees centigrade is used for cables installed prior to 1930 and 80 degrees centigrade for cables installed since 1930. The AEIC value for temperature is 74 degrees centigrade. The variations due to vintage are the result of changes in the nature of cable insulation and because in general the older cables are installed in cramped conduit systems without adequate expansion facilities.

Problems Arising in the Emergency Loading of Cables as Viewed by a Manufacturer's Engineer; *W. A. Del Mar (F '20) Habirshaw Cable and Wire division, Phelps Dodge Copper Products Corporation.* Herein are reviewed the influence which thermal resistivity of insulation, thermal emissivity of the sheath, and cables in ducts buried in the ground or in the air have on the current-carrying capacity of a cable. Explanation was given for limiting conductor temperature to 85 degrees centigrade, with reference to the hot spot along the circuit which usually is not easily located. Therefore, as in the cases of other electrical equipment, a maximum temperature which will not cause deterioration of the insulation is necessary for this hot spot and a deduction must be made for those locations at which the temperature can be determined and which invariably will be lower than the hot spot. Mr. Del Mar thinks that cables which operate over the present maximum operating temperature are living on "borrowed time" and that their ultimate life is decreased. This should be considered when setting up emergency ratings and the question "can we afford to do so" must be answered.

Use of Cable in Wartime; *Herman Halperin (M '26), Commonwealth Edison Company, Chicago, Ill.* Mr. Halperin refers to previous papers presented by him before AIEE, and in particular, his paper "Load Ratings of Cable—II," presented before the AIEE convention in June 1942. He repeats again the following statement in the June 1942 paper which is worth consideration by all interested in cable loading. "As a general proposition, one cannot be dogmatic about the allowable temperatures for a given underground cable circuit. Factors affecting the decision include age and condition of the cable and accessories, effect of heat on the properties of the materials in the circuit, magnitude of usual daily temperature range, size of manhole and training of cable therein, frequency of emergency loading, past history of loading of cable, relation of temperature and temperature range for normal loading to temperature and temperature range for emergency loading, number of cables in conduit, allowable conduit temperatures, thoroughness of field inspection and maintenance work, desired life of the underground circuit, and desired reliability of service. One factor or set of factors may allow one loading while another factor or set of factors for the same cable may allow less loading." Mr. Halperin's company has established maximum allowable operating temperatures for impregnated-paper-insulated cables operating at various voltages, which are tabulated in this paper.

Wartime Loading of Insulated Power Cables; *G. B. Shanklin (M '29), General Electric Company, Schenectady, N. Y.* Various ways to conserve copper in insulated wire and cable circuits are discussed. Reference is made to the effect of exceeding the standard temperature limits, stating that for each five to ten degree centigrade increase in normal daily load temperature, there is approximately a reduction of 50 per cent in the life of the cable insulation and double that in the failure rate. Tables giving suggested peacetime and wartime loadings for both normal and emergency operation for impregnated-paper-, varnished-cambric- and rubber-insulated cables are included. The paper also gives a table of 60-cycle short-circuit currents of 1.0-second duration for various conductor sizes and temperature rises above operating temperature.

Cable Loading for Normal and Emergency Conditions; *C. T. Hatcher (M '37), Consolidated Edison Company of New York, N. Y., Inc.* Normal and emergency ratings are determined on the basis of maximum loading on the feeder in question, and on the basis that other feeders will not be loaded up to their rating. The upper temperature used for emergency ratings of high-voltage paper-insulated cables are based on the results of laboratory and field tests made during 1934 to 1937. It was concluded that 100 degrees centigrade is the maximum safe operating copper temperature for paper cables. Varnished-cambric cables are not operated over the IPCEA limits because of lack of data on the aging characteristics of this type of insulation. In cases of extreme emergency, such as the loss of a generating station, or the shutdown of a network area, feeder loadings, of necessity, have been allowed to exceed the emergency ratings, apparently with no marked increase in failure rates. Emergencies of this nature, however, occur very infrequently. The failure rate on the system has not increased nor has there been a noticeable deterioration of insulation due to overheating since the above ratings have been used.

Mechanical Effect of Temperature Change in Lead-Covered Cables; *E. W. Oesterrich (A '42), Duquesne Light Company, Pittsburgh, Pa.* Mr. Oesterrich discusses the policy of "economy of plenty" during the prewar era to the "economy of scarcity" policy prevailing now, and how each factor concerned in the load rating of a cable must be considered. He refers to the recognition of the reduction in life expectancy and service reliability under present day conditions of availability of critical materials and equipment manufacturing production capacity.

An interesting description of studies made to reduce the number of sheath failures due to cable movement both from normal and emergency loadings is included, from which these conclusions are drawn:

1. Field surveys indicate that, theoretically, possible cable elongation under given operating temperatures

Future AIEE Meetings

Southern District Meeting
Roanoke, Va., November 16–18, 1943

National Technical Meeting
New York, N. Y., January 24–28, 1944

National Technical Meeting
St. Louis, Mo., June 26–30, 1944

is only developed in a few isolated locations on the system.

2. The use of certain types of fireproofing material and the elimination of friction points in the manhole cable supporting structure will minimize the formation of stress-concentration areas and thereby will increase the life expectancy of the cable sheath.

3. Life expectancy of cable sheaths on cables now in service in certain types of manholes can be increased to a point where other conditions supply the emergency-rating limitation. Rehabilitation or improvement when required can be accomplished without the use of materials on the critical list at present.

SECTION

Special Committee on Sections Manual Created

A special committee has been appointed to prepare a manual on Section operation and management for distribution to AIEE Section officers. The new committee was authorized by the board of directors at its meeting of June 24 in Cleveland, Ohio, when it approved a resolution passed by the Sections delegates attending the summer national technical meeting.

The resolution provided that two substantially bound copies of such a manual, covering all pertinent features of Section operation, such as duties of officers, suggestions of national committees, and other material assembled for ready reference, should be supplied by headquarters to each Section, one copy to be maintained by the chairman and one by the secretary. It provided further that the manual be arranged by numbered subjects in loose-leaf form to facilitate revision, and that it be passed on to incoming officers to assist them in their work.

Members of the new committee, appointed by President N. E. Funk, are: G. W. Bower and O. C. Brill, representatives of the Sections committee; John Mills and S. B. Williams, publication committee; M. D. Hooven and Robin Beach, technical program committee; J. H. Pilkington and E. P. Yerkes, membership committee; and H. E. Farrer and F. A. Lewis, headquarters staff representatives.

PERSONAL

W. B. Kouwenhoven (A '06, F '34) dean of the school of engineering, Johns Hopkins University, Baltimore, Md., has been appointed chairman of the AIEE Edison Medal committee for 1943–44. He served on that committee for 1935–37 and more recently has been a member since 1939. Doctor Kouwenhoven, who was born in Brooklyn, N. Y., January 13, 1886, received from Brooklyn Polytechnic Institute the degrees of electrical engineer in 1906 and mechanical engineer, *summa cum laude*, in 1907. In 1913 he earned a diploma in engineering, *summa cum laude*, from the Karlsrube Technische Hochschule, Baden, Germany, and in 1914 the degree of doctor of engineering, *magna cum laude*. From 1907 to 1910 he was on the faculty of Brooklyn Polytechnic Institute: as assistant in physics until 1907, and as instructor in physics and electrical engineering thereafter. During 1913–14 he was instructor in electrical engineering at Washington University, St. Louis, Mo. In 1914 he joined the staff of Johns Hopkins University as instructor in electrical engineering. He was made associate in electrical engineering in 1917. On leave of absence from the University during 1919–20, he was employed as engineering superintendent at the Winchester Repeating Arms Company, New Haven, Conn. He resumed his duties at the university as associate professor in 1920 and was appointed professor of electrical engineering and assistant dean of the school of engineering in 1930. In 1938 he became dean of the school of engineering. He has been consulting engineer to the United States Bureau of Mines and the United States Bureau of Standards. Author of numerous papers, he was especially honored for two of them by the International Electrical Congress in 1932 and by the Resistance Welders Manufacturers' Association in 1942. His many AIEE activities have included the offices of chairman of the Baltimore Section in 1930 and counselor of the Johns Hopkins University Branch from 1938 to 1941, and membership on the following committees: instruments and measurements, 1925–41 (chairman, 1933–36); Sections, 1925–34 (chairman, 1927–30); research, 1933–41 (chairman, 1936–38); Lamme Medal, 1938–41 (chairman 1939–41); telegraphy and telephony (now communication), 1919–20; electrophysics (now basic science), 1924–33; co-ordination of Institute activities, 1927–30; safety, 1933–43; electrochemistry and electrometallurgy, 1935–42 (chairman, 1941–43); award of Institute prizes, 1936–38; standards, 1940–43; Institute policy, 1940–42, application of electricity to therapeutics, 1941–43; technical program, 1931–38, 1941–43. Doctor Kouwenhoven served as vice-president of the Institute for 1931–33 and as a director for 1935–39.

C. L. Dawes

W. B. Kouwenhoven

W. R. Smith

W. R. Smith (M '18, F '30) safety engineer, Public Service Electric and Gas Company, Newark, N. J., has been appointed 1943–44 chairman of the AIEE committee on safety of which he has been a member since 1939. He was born in Charleston, S. C., February 23, 1885, and was graduated from Clemson Agricultural and Mechanical College in 1906 with the degree of bachelor of science in electrical engineering. In 1928 he received the degree of electrical engineer. During 1907 he was employed as secretary and assistant to the head of the engineering department at Clemson college. In 1908 he entered the employ of the Hartford Suspension Company, Jersey City, N. J., as draftsman. In 1909 he became manager of the company's New England offices, Boston, Mass., and in 1911 of its Newark office. In 1912 he was placed in charge of the department of design at Jersey City. During 1913 he was salesman for the White Motor Car Company, Newark. He commenced his association with the Public Service Company in 1914 in the electrical construction department. From 1917 to 1922 he was field engineer in charge of construction work. With the formation of the Public Service Production Company, Newark, in 1922 he became superintendent of electrical construction and in 1924 was appointed managing electrical engineer. In 1927 he was made assistant chief engineer. He held the latter position with the Newark branch of the United Engineers and Constructors, Inc., from 1928 to 1935. In 1938 he returned, as transmission construction engineer, to the Public Service Electric and Gas Company. Since 1938 he has been safety engineer. He is currently (1942–46) serving as a director of the Institute. He has been active on the following committees: publication, 1935–36; co-ordination of Institute activities, 1935–37; Alfred Noble Prize, 1936–37; finance, 1942–43; board of examiners, 1930–36 (chairman, 1934, 1936); technical program, 1935–37 (chairman 1935–36); award of Institute prizes, 1935–37 (chairman, 1935–36). In addition he was chairman of the New York Section for 1934–35, and secretary for 1932–33. He holds membership in the National Society of Professional Engineers, the Edison Electric Institute, the American Standards Association, the American Society of Safety Engineers, and the National Safety Council.

C. L. Dawes (A '12, F '35) associate professor of electrical engineering, Harvard University, Cambridge, Mass., has been appointed chairman of the AIEE committee on instruments and measurements for 1943–44. He has been a member of the committee since 1939. Professor Dawes was born November 13, 1886, at Somerville, Mass., and was graduated from Massachusetts Institute of Technology with the degree of bachelor of science in 1909. As a member of the staff of the Massachusetts Institute of Technology, Cambridge, he was assistant in physics in 1909, and assistant in electrical engineering in 1910. From 1911 to 1916 he was instructor in the graduate school of applied science, Harvard University. Securing a leave of absence in 1913 and 1914, he served as professor of electrical engineering in the postgraduate school of the United States Naval Academy, Annapolis, Md. From 1916 to 1919 he was instructor in electrical engineering at Harvard University and the Massachusetts Institute of Technology. In 1919 he became assistant professor of electrical engineering, graduate school of engineering, Harvard University, and in 1931 was made associate professor. He has been awarded Institute best paper prizes for several of his numerous technical papers and is the author of engineering textbooks as well. His research work has been chiefly in the field of insulation. A number of patents have been issued in his name. In addition to his teaching career, he has acted as consulting engineer for many manufacturing firms including: Simplex Wire and Cable Company, Cambridge, the New England Mica Company, Waltham, Mass., and the Albert and J. Manders Company, Boston, Mass. Besides serving as Institute vice-president for 1938–40, he has been a member of the following Institute committees: membership, 1936–38, Edison Medal, 1938–40, Lamme Medal, 1942–45, and technical program, 1942–43. He is also a fellow of the American Association for the Advancement of Science, and a member of the Society for the Promotion of Engineering Education and the American Association of University Professors.

H. A. Affel (A '18, F '41) assistant director of transmission development, systems development department, Bell Telephone Laboratories, New York, N. Y., has been appointed 1943–44 chairman of the AIEE committee on communication of which he has been a member since 1938. Born August 4, 1893, in Brooklyn, N. Y., he was graduated from the Massachusetts Institute of Technology with the degree of bachelor of science in 1914. He was employed from 1914 to 1916 as research assistant on telephone receiving circuits and high-voltage transmission in the department of engineering, Massachusetts Institute of Technology, Cambridge, Mass. He entered the American Telephone and Telegraph Company, New York, N. Y., in 1916 where he engaged in development work on multiplex telephone and telegraph systems. In 1919 he became a group head in the department of development and research in charge of carrier telephone and telegraph development work. From 1930 to 1934 he supervised work on problems connected with transmission development of carrier telephone systems. In the same capacity he was attached to the staff of Bell Telephone Laboratories in 1934. He was made toll transmission development director in 1935 and assistant director of transmission development transmission development department in 1938. In 1940 he was transferred to the systems development department. For two of his numerous technical papers he has received honorable mention in the Institute's national best paper prize awards. He was honored as a modern pioneer at the National Association of Manufacturers' celebration of the 150th anniversary of the United States patent system in 1940. He is also a member of the Institute of Radio Engineers, the Acoustical Society of America, and the American Association for the Advancement of Science.

W. C. Kalb (A '13, F '40) commercial engineer, carbon sales division, National Carbon Company, Cleveland Ohio, has been appointed chairman of the AIEE committee on the production and application of light for 1943–44. He has been a member of this committee since 1929. Born in Arcadia, Ohio, September 3, 1882, he was graduated from Ohio State University with the degree of mechanical engineer in electrical engineering in 1904. From 1904 to 1907 he was employed by the Columbus (Ohio) Pneumatic Tool Company as a mechanical engineer. He entered the employ of the National Carbon Company as electrical engineer in 1907. During 1910–11 he was general superintendent of Dunlap Engineering Company, Columbus. Returning to the National Carbon Company in 1911, he became assistant foreman and in 1913 he was made sales engineer. As managing engineer he joined the Corliss Carbon Company, Bradford, Pa., in 1919 and in 1920 became general manager. When the Corliss company was purchased by the National Carbon Company in 1926, he remained superintendent of the Corliss plant. In 1927 he was transferred to the carbon sales division of the company, responsible for automotive brush sales. Placed in charge of technical publicity in 1928, he became commercial engineer in 1940. He holds various patents on brushes and brush shunts and has published many technical articles. Mr. Kalb was chairman of the Cleveland Section for 1938–39 and for 1941–42 and Section secretary for 1936–37. He has been a member of the following committees: industrial and domestic power, 1918–22; electrochemistry and electrometallurgy, 1931–43 (chairman 1932–34); and technical program, 1932–34.

W. A. Lewis (A '27, M '39) director, school of electrical engineering, Cornell University, Ithaca, N. Y., has been appointed 1943–44 chairman of the AIEE committee on research of which he has been a member since 1941. He was born January 21, 1904, in Harriman, Tenn. Attending the California Institute of Technology on a Westinghouse scholarship, he received the degrees of bachelor of science in 1926, master of science in 1927, and doctor of philosophy, *summa cum laude*, in 1929. From 1920 to 1922 he was switchboard engineer with the Westinghouse Electric and Manufacturing Company, Los Angeles, Calif. As a graduate student he held the position of engineer in the wiring department of the California Institute of Technology, Pasadena. He was employed as central station engineer by the Westinghouse company at East Pittsburgh, Pa., from 1929 to 1939. In 1939 he was appointed director of the school of electrical engineering, Cornell University. He is the author of various technical articles and has received honorable mention in the Institute's national best paper prize awards. His AIEE committee memberships include: protective devices, 1933–43; power transmission and distribution, 1939–43; standards, 1941–42; technical program 1941–42, education, 1939–40, 1941–42; basic sciences, 1940–43 (chairman 1941–42). He is a member of Tau Beta Pi and Sigma Xi.

H. H. Race (A '24, F '39) research engineer, General Electric Company, Schenectady, N. Y., has been appointed 1943–44 chairman of the AIEE publication com-

W. C. Kalb

W. A. Lewis

H. A. Affel

R. W. Ager

M. J. McHenry

C. C. Levy

H. H. Race

mittee. Dr. Race has served on this committee since 1938. Born February 12, 1899, at Buffalo, N. Y., he was graduated from Cornell University in 1922 with the degree of electrical engineer and in 1927 received the degree of doctor of philosophy. From 1920 to 1922 he was instructor in the electrical-engineering laboratory at Cornell University, Ithaca, N. Y. In 1922 he became distribution engineer for the Philadelphia (Pa.) Electric Company. During 1922 and 1923 he was also instructor in the evening session of Drexel Institute, Philadelphia, Pa. He returned to the position of instructor at Cornell University in 1923 and in 1927 he became assistant professor. He joined the General Electric Company as research engineer in 1929. As such he has been responsible for work on the electrical properties of liquid and solid insulating materials. He has held the offices of chairman, 1935–36, and secretary, 1932–34, in the Schenectady Section. His committee activities include: research, 1930–41; basic sciences, 1933–43 (chairman, 1942–43); Sections 1936–40, 1943 (chairman, 1938–40); planning and co-ordination, 1938–40; standards, 1942–43; and technical program, 1942–43. Author of numerous technical articles, he is also a member of the American Association for the Advancement of Science, the American Physical Society, and the National Research Council.

M. J. McHenry (A '11, M '20) director of sales promotion, Hydro-Electric Power Commission, Toronto, Ont., has been appointed 1943–44 chairman of the AIEE committee on transfers of which he has been a member since 1941. Born in Catasauqua, Pa., August 8, 1888, he was graduated from McGill University with the degree of bachelor of science in 1910. From 1910 to 1912 he was engaged in the design of hydroelectric power stations with Smith, Kerry, and Chase, Consulting Engineers, Toronto. He joined the Canadian General Electric Company, Toronto, as sales engineer in 1912 and became assistant manager of the Toronto district office in 1916. From 1918 to 1924 he was manager and secretary-treasurer of the Walkerville (Ont.) Hydro-Electric System. He was made manager of the Ferranti Electric Company, Ltd., Toronto, in 1924 and manager of the United States sales department of the Canadian General Electric Company in 1926. In 1930 he was appointed district manager for Ontario, and in 1938 director of sales promotion for the Hydro-Electric Power Commission. For 1937–39 he served as vice-president of the Institute and has been a member of the committee on general power applications, 1920–22, 1937–38; and the committee on industrial power applications, 1938–43. He is a member of the Association of Professional Engineers of Ontario, the Electric Club of Toronto and the Electric Service League of Toronto.

R. W. Ager (A '24, M '41) associate professor, school of electrical engineering, Cornell University, Ithaca, N. Y., has been appointed chairman of the 1943–44 committee on basic sciences of which he has been a member since 1941. Born January 30, 1898, in St. Peter, Minn., he received from the California Institute of Technology the degrees of bachelor of science in electrical engineering in 1922 and doctor of philosophy, *magna cum laude*, in 1933. From 1923 to 1931 he was inspector and research assistant with the Southern California Edison Company, Ltd., Los Angeles. In 1934 he became assistant professor of electrical engineering at the University of California, Berkeley. He was appointed associate professor of electrical engineering in charge of the high-voltage laboratory at Cornell University in 1941. He has published several technical papers and is a member of the Society for the Promotion of Engineering Education, Tau Beta Pi, Sigma Xi, and Eta Kappa Nu.

C. C. Levy (A '33) industrial engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed chairman of the AIEE committee on electrochemistry and electrometallurgy for 1943–44. Mr. Levy has served on the committee since 1934 and held the chairmanship for 1940–41 as well. Born September 18, 1886, in Lucea, Jamaica, B. W. I., he attended Toronto University. He commenced his career as a switchboard operator for the New York (N. Y.) Edison Company, in 1905 and 1906. During 1912–13 he worked as electrical draftsman with the Canadian General Electric Company, Toronto, Ont. He joined the Westinghouse Electric and Manufacturing Company, in 1913 as switchboard draftsman and from 1916 to 1920 he was designing engineer with the switchboard department. In 1920 he was placed in charge of switchboard drafting and in 1922 became automatic switching engineer. Since 1930 he has been engaged in application engineering specializing in electrochemical and chemical industries.

J. C. Damon (A '05, M '13) colonel, United States Army, on the staff of the price-adjustment section, War Department, Washington, D. C., has been retired from the Army. A graduate of Massachusetts Institute of Technology, Colonel Damon started his career in the utility field as design and construction engineer from 1905 to 1913 with the Chicago (Ill.) Telephone Company, the Telluride Company of Colorado, the Trinidad Electric Transmission Railway and Gas Company, and the Electric Bond and Share Company, New York, N. Y. He was assistant chief engineer for the Utah Power and Light Company, Salt Lake City, from 1913 to 1917. During World War I he rose from the rank of captain to that of major in the United States Army. Most of his service was in the power section of the War Industries Board. From 1919 to 1922 he worked on development plans for the West Penn Power Company. In 1922 he joined Stone and Webster, Boston, Mass., and in 1924 the American Brass Company. From 1927 to 1933 he was an executive in the construction division of Jackson and Moreland, Boston. He was made chief engineer of the Public Service Commission of Wisconsin in 1933. Appointed to the Securities and Exchange Commission, Washington, in 1935, he was supervising engineer of its Public Utilities Division until 1941. In 1941 he returned to active duty as major and chief of the Advance Planning Unit Construction Division, Office of the Quartermaster General. Later he was made chief of the power branch of the Army–Navy Munitions Board. Promoted to lieutenant colonel and finally colonel in 1942, he was transferred to the conservation branch of the Production division of the Army Service Forces. In 1943 he

was attached to the price-adjustment section.

D. T. May (M '28) mechanical-apparatus engineer, Bell Telephone Laboratories, Inc., New York, N. Y., has retired. After receiving his bachelor of science degree in mechanical engineering from the University of Illinois in 1905, Mr. May joined the Western Electric Company, Chicago, Ill., as a student engineer. In 1909 he was transferred to the company's physical laboratory in New York. During 1910 and 1911 he was a group head at the laboratory. From 1911 to 1917 he was engaged in designing and testing electrical protective apparatus and systems and studying inductive interference. He continued in this field in a supervisory position after 1917. Moving to Bell Laboratories in 1925, he became department head in the general development laboratory in charge of mechanical and electrical analysis of apparatus. In 1933 he added the supervision of materials investigations to his duties and in 1935 was named mechanical-apparatus engineer. A number of patents have been issued in his name and he has represented Bell Laboratories at various times on committees of the Edison Electric Institute, the American Society for Testing Materials, the American Standards Association, and the Association of American Railways.

J. H. Davis (A '03) chief engineer of electric traction, Baltimore and Ohio Railroad Company, Baltimore, Md., has retired. Since he received the degree of electrical engineer from the University of Arkansas in 1901, Mr. Davis has been connected with the railroad industry. His first position was assistant engineer with the Choctaw, Oklahoma, and Gulf Railroad in 1901. Joining the Pennsylvania Railroad, Altoona, Pa., in 1901 as draftsman and engineer, he became assistant electrical engineer in 1905, and electrical engineer in 1908. He had been chief engineer of electric traction for the Baltimore railroad since 1925. As such he designed the first air-conditioned railway passenger car in 1929, and also adapted air conditioning to storage bins. In 1932 he was granted authority by the Baltimore Railroad to install a research plant for the further development of his radio-wave method of exterminating insects in grain and increasing its germination, growth, and yield properties.

W. F. Sims (A '20, F '33) chief electrical engineer, Commonwealth Edison Company, Chicago, Ill., has retired. He commenced his engineering career as assistant engineer with the Chicago (Ill.) Telephone Company from 1897 to 1901. As construction engineer, he worked for the Chicago Edison Company from 1901 to 1906. In 1907 he became field engineer of the Board of Supervising Engineers of Chicago Traction and in 1911 joined Stone and Webster Engineering Corporation, Boston, Mass., as construction engineer. He was associated with William McMunn, consulting engineer, Chicago, during 1915 and 1916. He was made field engineer for the Commonwealth Edison Company in 1916, and inside plant engineer in 1930. In 1932 he was appointed chief electrical engineer.

R. H. Manahan (M '22) chief of the electrical division, building and safety department, City of Los Angeles, Calif., has retired. Mr. Manahan, an 1895 graduate of Stanford University, started his career in the office of the chief engineer of the Los Angeles Railway Company from 1895 to 1897. He worked on underground construction and switchboard construction for the Southern California Edison Company Ltd., Los Angeles, from 1897 to 1899. In the latter year he entered the employ of the City of Los Angeles as electrical inspector. In 1901 he was made head of the city's electricity department which was later incorporated into the building and safety department.

Millard Westrate (A '37) formerly electrical engineer, Commonwealth and Southern Corporation, Jackson, Mich., has been appointed chief engineer, Communication Equipment and Engineering Company, Chicago, Ill. Receiving the degree of bachelor of science from the University of Michigan in 1930, Mr. Westrate was employed in the frequency change department of the Consumers Power Company, Jackson. In 1935 he became power sales engineer. Since 1936 he has been engaged in special studies in the electrical-engineering department of the Commonwealth and Southern Corporation.

G. M. Armbrust (A '11, F '33) formerly assistant chief electrical engineer, Commonwealth Edison Company, Chicago, Ill., has been appointed chief engineer of that company. Mr. Armbrust has been connected with the Edison company since 1902 when he was employed as a draftsman. He became chief draftsman in 1912, staff engineer in 1919, and system development engineer in 1932. Later in 1932 he was appointed assistant chief electrical engineer. He is a member of the Western Society of Engineers. **W. G. Kelley** (A '08, F '26) plant design engineer since 1932, will succeed Mr. Armbrust as assistant chief electrical engineer. Mr. Kelley joined the Edison company in 1901.

W. J. Russell (M '37) formerly manager of engineering, electric-appliance division, Westinghouse Electric and Manufacturing Company, Mansfield, Ohio, has been appointed vice-president in charge of engineering for Landers, Frary and Clark, New Britain, Conn. Coming to the United States from Scotland in 1920, Mr. Russell joined the Westinghouse Electric and Manufacturing Company, East Springfield, Mass., in 1923 as tool and die maker. In 1926 he became time-study engineer and in 1928 manufacturing engineer. He was transferred to Mansfield as supervisor of manufacturing operations in 1931. In 1933 he was appointed manager of engineering.

D. J. O'Conor, Jr. (A '38) president, Formica Insulation Company, Cincinnati, Ohio, has been appointed one of the five members of the plastics industry to serve on a national industry Advisory Committee for Plastic Thermosetting Laminates.

S. G. Hibben (A '34) director of applied lighting, Westinghouse Lamp Division, Bloomfield, N. J., has been elected treasurer of the Illuminating Engineering Society.

N. M. Levinson (A '42) junior engineer, Rural Electrification Administration, St. Louis, Mo., and ensign, United States Naval Reserve, has been called to active duty.

C. W. Leihy (A '30, M '38) formerly engineering editor of *Electrical West* and *Electric Light and Power* is now a lieutenant colonel in the United States Army.

P. S. Millar (A '03, M '13) president of the Electrical Testing Laboratories, New York, N. Y., has been elected president of the New York Electrical Society.

V. K. Zworykin (M '22) associate director, RCA Research Laboratories, Camden, N. J., recently was elected a member of the National Academy of Sciences.

OBITUARY • • • •

Gustavus Adolphus Anderegg (A '04, F '30) retired cable-development engineer, Bell Telephone Laboratories, Inc., New York, N. Y., died August 14, 1943. Born March 30, 1873, at Ragersville, Ohio, he received the degree of bachelor of science from Oberlin College in 1899. In 1900 he received the degree of bachelor of arts and in 1902 the degree of master of arts from Harvard University. From 1902 to 1904 he worked in the development laboratory of the Western Electric Company, first in Chicago, Ill., and later in New York, N. Y. During 1904–05 he was temporary instructor of electrical engineering at Harvard University, Cambridge, Mass. From 1905 to 1908 he served as associate professor of electrical engineering at Ohio State University, Columbus. He returned to the Western Electric Company in 1908 and a year later was transferred to Chicago where he was directly responsible for investigations leading to the manufacture of the first lead-covered toll telephone cable employing loaded phantom circuits. In 1913 he was placed in charge of all lead-covered cable developments in the engineering department of the Western Electric Company and after 1925 at Bell Laboratories. Returning to New York in 1918 he added the duties of transmission branch engineer and head of the physical laboratory to his cable-development work for a time. In the years following he spent much time in England and Germany in

connection with the development of submarine cables. The first high-speed permalloy-loaded telegraph cable which revolutionized ocean cable telegraphy was developed through his efforts. This cable was laid between New York and the Azores in 1924. Other important cables manufactured and laid under his supervision include one from Key West, Fla., to Havana, Cuba, in 1922; one from Fanning Island to Suva in the Fiji Islands and one from the Azores to Emden, Germany, in 1926. He was joint holder of several patents and a member of the American Association for the Advancement of Science, the Montclair Society of Engineers, the Harvard Engineering Society, and the Telephone Pioneers of America.

John Emile Boesch (A '08, M '13) owner, Oficina Tecnica "Rotor," San Salvador, Salvador, died July 7, 1943. Born May 21, 1878, in Winterthur, Switzerland, he was graduated from the Technical College of Winterthur as an electrical and mechanical engineer in 1899. As draftsman and designer he was employed by Brown Boveri and Company, Switzerland during 1899 and 1900. In the same capacity he worked for the French Westinghouse Company, Havre, from 1900 to 1902, and for the British company at Manchester, England, from 1902 to 1905. During 1905 and 1906 he served as designer for C. O. Mailloux, consulting engineer, New York, N. Y. While in this position one of his projects was the steam-plant layout of the Engineering Societies' Building in New York. After the earthquake of 1906 he redesigned several substations and generating stations for the Underground Railroad, San Francisco, Calif. He worked as designer and chief inspector for the Mexican Light and Power Company, Mexico City, from 1907 to 1910. In 1910 he became distributing engineer for the British Columbia Electric Railway, Ltd., Vancouver. In 1917 he went to Peru as electrical and mechanical engineer for the Cerro de Pasco Mining Company, Lima. From 1918 to 1927 he was technical engineer for the Cia. Alumbrado, Iniquique, Chile. Joining the Oficina Tecnica, San Salvador, Salvador, in 1927 as engineer, he became its owner in 1934.

William E. Rook (A '43) engineer, American Telephone and Telegraph Company, Chicago, Ill., died July 24, 1943. He was born at Chicago, September 11, 1904. In 1923 he was employed as communications engineering draftsman at the Hawthorne plant of the Western Electric Company, Cicero, Ill. Joining the American Telephone and Telegraph Company in 1925, he was engaged chiefly in outside plant installations. For two periods, from 1932 to 1936 and again from 1938 to 1940, he devoted his time to study of transmission-line difficulties and their correction. Since 1942 he had been engineer in charge of the drafting room.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on September 23, 1943, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Butcher, C. A., Mgr., Pacific Coast Dist. Mfg. & Repair Dept., Westinghouse Elec. & Mfg. Co., Emeryville, Calif.
Hollister, F. H., chief electrical engr., Sargent & Lundy, Chicago, Ill.
Hunt, J. H., director, New Devices Section, General Motors Corp., Detroit, Mich.
Hynes, L. P., electrical and mechanical engr., Camden, N. J.
Lacy, T. N., vice-pres. and general mgr., Michigan Bell Telephone Co., Detroit, Mich.

To Grade of Member

Bany, Herman, application engr., General Electric Co., Philadelphia, Pa.
Barry, R. L., electrical engr., Research Dept., Goodman Mfg. Co., Chicago, Ill.
Bean, G. W., chief engr., Texas Electric Service Co., Fort Worth, Tex.

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical District. Any member objecting to the election of any these candidates should so inform the national secretary before October 31, 1943, or December 31, 1943, if the applicant resides outside of the United States or Canada.

To Grade of Fellow

Burt, R. C., Lockheed Aircraft Corp., Burbank, Calif.

To Grade of Member

Ayers, J. W., C. P. Clare & Co., Chicago, Ill.
Caminiti, P. A., Brewster Aero. Corp., Long Island City, N. Y.
Clarke, C. G. C. (Re-election), The English Elec. Co., Ltd., Stafford, England.
Dudley, B. (Re-election), McGraw-Hill Pub. Co., New York, N. Y.
Duttera, W. S., Natl. Broadcasting Co., New York, N. Y.
Hurd, B. B. (Re-election), Hatfield Elec. Co., Oil City, Pa.
Ikola, E. (Re-election), Koppers Co., Pittsburgh, Pa.
Johnston, B. H., Moloney Elec. Co. of Canada, Ltd., Montreal, Que., Can.
McGuire, D. B. (Re-election), Rockland Light & Power Co., Middletown, N. Y.
Mosman, G. R. (Re-election), Amer. Tel. & Tel. Co., Chicago, Ill.
Muth, A. J. (Re-election), Albert Kahn Associated, Detroit, Mich.
Puri, N., Military English Services, Punjab, India.
Read, W. V. (Re-election), Curtiss-Wright Corp., Caldwell, N. J.
Rimmer, G. M., City Gas Works, Birmingham, England.
Shoard, W. H., Geo. A. Fuller Co., Chicago, Ill.
Thacker, R. S., Cannon Elect. Dev. Co., Los Angeles, Calif.
Tuttle, A. N., Walworth Co., Inc., East St. Louis, Ill.
VanHoose, J. E., Rural Elec. Admin., St. Louis, Mo.
Wilson, C. C., Ward Leonard Elec. Co., Mt. Vernon, N. Y.

19 to grade of Member

To Grade of Associate

United States and Canada

1. NORTH EASTERN

Albach, C. R. (Re-election), U. S. Engineer Office, Buffalo, N. Y.
Brown, H. A., Rochester Gas & Elec. Corp., Rochester, N. Y.
Maginnis, F. J., Gen. Elec. Co., Schenectady, N. Y.

2. MIDDLE EASTERN

Augsburger, H. M., Kimble Glass Co., Vineland, N. J.
Braun, H. J., Westinghouse Elec. & Mfg. Co., Lima, Ohio.
Byrd, H. L., Gen. Elec. Co., Philadelphia, Pa.
Derrick, W. A., Philco Corp., Sandusky, O.
Foltz, H. M., Jr., Lowry Elec. Co., Inc., Williamsport, Pa.
Grim, C. D. (Re-election), Gilbert Associates, Inc., Reading, Pa.
Lippitt, H. F., 2nd Lieut., USNR, Washington, D. C.
Orellana, I. G., Republic Steel Corp., Cleveland, Ohio
Woods, W. O., Gen. Elec. Co., Erie, Pa.
Wynkoop, W., Bethlehem Steel Co., Bethlehem, Pa.

3. NEW YORK CITY

Bachand, G. R., Westinghouse Elec. & Mfg. Co., Bloomfield, N. J.
Brodsky, L., Jr., Federal Tel. & Radio Corp., Newark, N. J.
Bulsing, W., Burns & Roe, Inc., New York, N. Y.
DeCew, A. E., Ward Elec. Co., Mt. Vernon, N. Y.
Emigh, C. R., Westinghouse Elec. Elev. Co., Jersey City, N. J.
Fitchen, J. H. (Re-election), Burns & Roe, Inc., New York, N. Y.
Florez, H., Cons. Radio Engr., 41–29 41st St., Long Island City, N. Y.
Hickstein, Beatrice A., Western Elec. Co., Kearny, N. J.
MacCoun, T. D., Link Radio Corp., New York, N. Y.
Scheib, J., Jr., Ward Leonard Co., New York, N. Y.
Schram, R. E., Aluminum Co. of America, Maspeth, L. I., N. Y.
Solbrig, A. L., 1st Lt., U. S. Army, Allenhurst, N. J.
Squire, E. M. (Re-election), Mfrs. Tech. Rep., New York, N. Y.
Tiernan, T. F. (Re-election), American Dist. Tel. Co., New York, N. Y.
Wappler, A. C., Wappler, Inc., New York, N. Y.

4. SOUTHERN

Erlandson, N. H., Carolina Power & Light Co., Raleigh, N. C.
Liverman, R. B., Newport News Shipbuilding & Dry Dock Co., Newport News, Va.
McCracken, H. R., T.V.A., Chattanooga, Tenn.
Purdum, W. F., Waterman Steamship Corp., Mobile, Ala.
Simpson, J. G., Westinghouse Elec. & Mfg. Co., Chattanooga, Tenn.

5. GREAT LAKES

Angelakos, D. J., University of Notre Dame, Notre Dame, Ind.
Boldt, R. E., U. S. Navy Dept., Milwaukee, Wis.
Glyptis, N., Bell & Howell Co., Chicago, Ill.
Hastings, H. R., A.C. Spark Plug Div., G.M. Corp., Flint, Mich.
Kalina, G. F., Gen. Motors Corp., Detroit, Mich.
Lehrkind, A., Allis-Chalmers Mfg. Co., West Allis, Wis.
Linfor, J. F., Penn Elec. Switch Co., Goshen, Ind.
Mauver, G. N., U. S. Navy Dept., Milwaukee, Wis.
Nader, J., Eicor, Inc., Chicago, Ill.
Quigley, A. J., University of Nore Dame, Notre Dame, Ind.
Saunders, H. O. (Re-election), Illinois Bell Tel. Co., Chicago, Ill.
Scalone, J. M., Allis-Chalmers Mfg. Co., West Allis, Wis.
Scofield, D. W., Electromaster, Inc., Detroit, Mich.
Stringer, W. A., Gen. Motors Corp., Detroit, Mich.
Wadel, A. G., Studebaker Aviation, South Bend, Ind.
Zamsky, J., Square D. Co., Milwaukee, Wis.

7. SOUTH WEST

Boughan, J. J. Gordon, Turnbull, Sverdrup, & Parcel, St. Louis, Mo.
Garland, C. E., Texas Elec. Serv. Co., Fort Worth, Tex.
Gates, L. B., Rural Elec. Adm., St. Louis, Mo.
Heins, E. F. (Re-election), Southwestern Bell Tel. Co., St. Louis, Mo.
Kesler, J. P., West E. & M. Co., Kansas City, Mo.
Moszcynski, S., Rural Elec. Adm., St. Louis, Mo.
Neukomm, W. H., Southwestern Bell Tel. Co., Tulsa, Okla.
Shiozawa, S., Rural Elec. Adm., St. Louis, Mo.
Simmons, E. J., Maloney Elec. Transformer Co., St. Louis, Mo.
Strojny, J. S., Rural Elec. Adm., St. Louis, Mo.
Sweet, E. A., Union Electric Co. of Mo., Webster Groves, Mo.
White, C. E., Rural Elec. Adm., St. Louis, Mo.

8. PACIFIC

Newman, J. E., Signal Office, San Francisco, Calif.

9. NORTH WEST

Baker, A. M., Lieut. (j.g.), USNR, Tacoma, Wash.
McCoomba, R. E., Great Northern Ry., Wenatchee, Wash.
Riechel, D. A., Pacific Tel. & Tel. Co., Portland, Oreg.

10. CANADA

Gillett, G. H., Canadian Gen. Elec. Co., Ltd., Montreal, Que., Can.

Elsewhere

Das, S. C., Indian Institute of Science, Bangalore, India.
Mare, A. J., Dubilier Condenser Co., Birmingham, England.
Vilela, J. O. C., Brazil Govt., Rio de Janeiro, Brazil, S. A.

Total to grade of Associate
United States and Canada, 66
Elsewhere, 3

OF CURRENT INTEREST

U. S. Army Requests Radio and Photographic Equipment

Although hundreds of short-wave sets and other amateur radio apparatus, and scores of fine cameras which once belonged to private citizens, now are used by Signal Corps units of the Army Service Forces, even greater quantities of this type of equipment are needed.

Purchases of radio equipment from individuals are confined to certain high-grade or scarce instruments which no longer are manufactured or which are needed in greater quantities. The list of "wanted" instruments ranges from standard and commercial short-wave sets to ordinary meters. The greatest need, however, is for testing equipment: oscilloscopes, signal generators, and tube checkers.

In the photographic field, good lenses, especially larger telephoto lenses, and sound cameras are needed most. High-grade movie cameras, both 35- and 16-millimeter, professional press and miniature still cameras, exposure meters, range finders, pack adapters, and cut film holders also are on the photographic list.

All material is shipped to troops overseas or to Army training schools, or allocated to the Federal Bureau of Investigation. Owners who wish to sell radio or photographic equipment to the Army Signal Corps should write to the Emergency Purchase Section, Philadelphia Signal Corps Procurement District, 5000 Wissahickon Avenue, Philadelphia, Pa. Letters to that office listing the equipment for sale are promised prompt attention.

Civil Service Commission to Fill Many Openings for Draftsmen

Over a hundred draftsmen are being sought by the United States Civil Service Commission for Federal agencies whose work is necessary to the prosecution of the war. Particularly wanted are ship, electrical, and mechanical draftsmen, as well as topographic draftsmen. In addition, the Treasury Department and the War Production Board can utilize statistical draftsmen.

Qualified engineering draftsmen in any field are urged to apply. Agencies with the most pressing needs are the Navy Department, the Coast and Geodetic Survey of the Department of Commerce, and the Geological Survey of the Department of the Interior. Most of the positions are in Washington, D. C., but some vacancies exist throughout the United States and its possessions.

Salaries range as high as $3,163 a year including pay for 8 hours overtime incorporated in the 48-hour Federal work week. For the higher-paying positions in all fields, experience or study in drafting appropriate to the grade of the position is necessary. Persons now employed at their highest skills should not apply as Federal appointments are made in accordance with War Manpower Commission policies and employment stabilization plans.

Those interested may secure Announcement 283 and application forms from first- and second-class post offices; from Civil service regional offices; or from the United States Civil Service Commission. Applications should be forwarded to the United States Civil Service Commission, Washington 25, D. C.

Variety of Power Units Employed by Signal Corps

As many as 60 different types of gasoline- or Diesel-engine power units are employed by the Signal Corps, United States Army Service Forces, for ground use alone. They range all the way from the 45-pound 300-watt portable type which a soldier can easily carry in his pack and which supplies energy for a special telephone system, to a 50,000-watt special-purpose power unit. Some have particular uses, and some are designed for a multiplicity of purposes. All have two things in common: they are built to stand up under any climatic handicaps, and are designed not to create radio interference.

As the Signal-Corps power units may follow the United States troops into all parts of the world, they are tested to operate at temperatures ranging from 40 degrees below zero to 130 degrees above zero, Fahrenheit. Auxiliary starting aids, which apply heat to the crankcase, intake manifold carburetor, and battery, are used for starting the power units in cold climates. Self-starters are used on most of the larger units, some of which may be operated by remote control, while rope starters are provided for the smaller equipment. Similarly, water-cooling is provided on the majority of larger equipment, air-cooling on the smaller ones.

Canada Expands Power Supply to Increase War Production

Canada's great resources of electric power provide one of the basic reasons why the Dominion now holds fourth place among the United Nations as a war producer, Honorable C. D. Howe, minister of munitions and supply, said recently in a report to the House of Commons on Canada's manufacturing progress.

Since 1938, when Canada's power installations, developed over a period of 45 years, totaled 7,155,000 horsepower, new wartime developments, including the enormous Shipshaw undertaking and certain other projects not yet completed, will have added an effective electrical capacity of 1,870,000 horsepower.

Since the beginning of the war, interconnections between power systems have been made more elastic and of greater capacity. Power has been loaned from time to time between the United States and Canada, transmitted to the United States at Niagara and taken from the United States at Beauharnois, or vice versa, depending on the needs of the moment.

In Ontario, production has been increased materially by the completion of the Big Eddy and Madawaska developments, and installation of the submerged weir in the Niagara River. The De Cew Falls development is nearing completion. In Quebec, the Shipshaw development, alone, has increased installations this year by 600,000 horsepower, and all the power companies have added to their output. In Alberta, the Minnewanka project has been completed, and in British Columbia, the Brilliant development is proceeding.

In all the provinces improved storage facilities, together with the installation of new machinery, have made more power available. The gas situation also has been improved by additional drilling in southwestern Ontario and by completion of a part of the new coke-oven gas plant at Hamilton, Ont.

Resources of Occupied Europe Absorbed by Nazi Industrialists

Nazi big business is rapidly swelling the profits of plunder through the absorption of the electric-power resources and light-metal industries in occupied countries, especially Norway and the Balkans, according to the latest report from the Office of War Information survey of the economic invasion of Europe which has followed in the wake of military conquest. In addition to this appropriation, a single German company, Kontinentale Oel A.G., controlled by a business alliance of Nazi party leaders and important German bankers and industrialists, holds a virtual monopoly over the entire oil business in the conquered countries of Europe.

A key firm in the Norwegian aluminum industry, A.S. Norsk Lettmettall, in Oslo, is almost completely dominated by German interests, three firms each owning one third of its capital. Of these firms, two are German: I.G. Farbenindustrie, the great German dye trust, and the Nordische Aluminum A.G., in Berlin, controlled by the German Air Ministry. The third firm, Norsk Hydro A.G., is held partly by Germans, partly by Norwegians. I.G. Farbenindustrie now operates the great indus-

trial center of Rjukan, which includes Norway's largest electric-power station as well as important chemical industry plants.

In the Balkans the Nazis have concentrated on developing full electrification with consequent profits to German firms. The German company, Energieversorgung Suedsteiermark, which absorbed the electrical enterprises in northwestern Yugoslavia, is now building a 100-kv cable between Reichenberg and Zagreb. In eastern Europe, the Nazis have set up a number of new companies which share profits of electrical development with the older German concerns. At the same time these older concerns are also erecting plants for production and distribution of electric power, and for the sale of electrical products.

Kontinentale Oel, capitalized at 80,000,000 marks ($32,000,000), operates only outside Germany, chiefly in southeastern Europe. Within a few months after it began operations, it had control of over 15 per cent of all Rumanian oil capital. Today there is probably not a single oil company in Rumania that is not subject to the German combine.

The Hungarian oil industry is controlled through one of the major stockholders in Kontinentale Oel, Wintershall A.G. Kontinentale's monopoly over the oil interests of Poland is controlled through a new subsidiary, Karpathan Oil, A.G.

Data in this report were assembled by OWI analysts from reports of Government agencies, and from materials appearing in the European press and radio.

Conrad N. Lauer, Founder of Hoover Medal, Dies

Conrad Newton Lauer, who donated the trust fund for the periodical award of the Hoover Medal "to a fellow engineer for distinguished public service," died August 2, 1943.

The Medal, which was awarded first to Herbert Hoover (HM '29) in 1930, has been presented four times to AIEE members. The second award of the Medal was made to Ambrose Swasey (HM '28) in 1936, the fourth to Gano Dunn (F '12) in 1939, and the sixth award to Gerard Swope (F '22) in 1942. Medalists are selected by a board of award representing the national societies of civil, mining, and metallurgical, mechanical, and electrical engineers.

Doctor Lauer was born November 25, 1869, in Three Tuns, Montgomery County, Pa., and was educated at public and private schools in his native county. He was awarded the honorary degrees of mechanical engineer, by Stevens Institute of Technology in 1930, and doctor of laws, by the University of Pennsylvania in 1940.

He was employed first by the Link-Belt Company from 1893 to 1902 in various positions from time clerk to acting superintendent. In 1902 he joined the firm of Dodge and Day, Philadelphia, Pa., as industrial engineer. When this firm was incorporated as Day and Zimmermann in 1916, he was made treasurer, general manager, and director. Later he became vice-president of the firm, and remained with it and its successors until 1929. In the latter year he was appointed president and director of the Philadelphia Gas Works. He resigned the presidency about a year ago and became chairman of the board.

He served as director of several steel companies, Cyrus Fogg lecturer at Princeton University, and special lecturer at the University of Pennsylvania at various times.

A past-president of the American Society of Mechanical Engineers, he was also a member of the American Gas Association, the Pennsylvania Chamber of Commerce, the American Academy of Political and Social Science, the Newcomen Society, the Franklin Institute, the Pennsylvania Society of Fine Arts Society, the Civic Safety Fund of Philadelphia, the boards of award for the Hoover and John Fritz Medals, and the Industrial Research and Development Bureau.

NRC Chemistry Committee Issues Review of Insulation

A 72-page pamphlet, "Contributions of the Chemist to Insulation Research for January 1942–January 1943," has been issued by the committee on chemistry of the National Research Council's Conference on Electrical Insulation.

Each of the six articles in the annual review, which is prepared to stimulate interest in insulation problems as well as to aid the insulation engineer, contains an extensive bibliography. In the current issue the field of anomalous electrical dispersion, and progress in rubber insulation are reviewed. Also treated are insulating paper, synthetic-plastic electrical insulation, and chemical progress on insulating oils. A section on ceramic and glass insulation has been added for the first time.

Copies may be obtained without charge, as long as the supply lasts, from G. T. Kohman, chairman of the committee on chemistry, Bell Telephone Laboratories, Murray Hill, N. J.

Merchant Marine Needs More Men

With each new invasion and newly delivered ship calling for additional skilled merchant seamen, the demands on that service grow heavier. On it rests the responsibility for delivering the gasoline, food, tanks, planes, guns which will insure the United Nations superiority on the fighting fronts.

Men who have been issued certificates for service in the United States merchant marine at any time in the past are urged by Marshall Dimock, assistant deputy administrator for recruitment and manning of the War Shipping Administration, to consider returning to the merchant marine service. In recent months, reports Mr. Dimock, more than 20,000 men of various professions and trades have returned to merchant marine posts, which helped the war effort more directly than their civilian jobs.

From a potential working force of 500,000 men who have been issued certificates for service since 1937, the merchant marine is endeavoring to recruit the mates, engineers, and able-bodied seamen, so badly needed at present. Mr. Dimock pointed out that 42 skilled men are needed to operate each of the five ships now completed daily.

Applicants for merchant marine berths may write the Recruitment and Manning Organization, Washington, D. C., or apply at the nearest United States Employment Service office.

NEMA Revises Brush Standards. A new edition of, "Carbon, Graphite and Metal-Graphite Brush Standards" (Publication 43-85), which supersedes the 1934 edition, has been published by the National Electrical Manufacturers Association. Standard dimensions and tolerances for carbon, graphite, and metal-graphite brushes, as well as standards for associated parts of brushes—cables, clips, and connections—are covered by the text. Uniformity of terminology is given attention in a special section devoted to definitions. Copies of the 16-page illustrated pamphlet may be obtained from NEMA, 155 East 44th Street, New York, N. Y., at 25 cents per copy.

Brazil's Power Supply Expanded for New Aluminum Industry

The first generators and transformers for power stations which will generate 6,000 kw of power for Brazil's new aluminum industry are now being installed, according to officials of the International General Electric Company.

When in 1940 the 1,600-odd tons of aluminum which Brazil imported annually from the United States were cut off by the enormous demands of the domestic aircraft industry, the Brazilian government laid plans to speed development of its 81 known deposits of bauxite estimated to contain approximately 150,000,000 tons. Electro Quimica Brasilera, a local power utility, made plans to enlarge its power facilities at three points—Saramenha, Caboleo, and Funil—in order to serve a projected aluminum plant near Ouro Preto, an important center in the state of Minas Geraes, which alone contains an estimated 120,000,000 tons.

Heretofore, Brazilian aluminum output, confined to the yield of surface mines, has been used mainly in the production of insecticides and of sulphate of aluminum for purifying Brazilian and Argentine water supplies. Eventually the Brazilian government expects to organize an aircraft industry for producing cargo planes that will be used in getting supplies to and from the interior.

Future Meetings of Other Societies

American Institute of Chemical Engineers. 36th annual meeting, November 15–16, 1943, Pittsburgh, Pa.

American Institute of Mining and Metallurgical Engineers. Petroleum division, October 21–22, 1943, Los Angeles, Calif. Industrial minerals division, October 21–23, 1943, Wilmington, Del. Joint fuels conference, October 28–29, 1943, Pittsburgh, Pa. Annual meeting, February 20–24, 1944, New York, N. Y.

American Society of Heating and Ventilating Engineers. 50th annual meeting, January 31–February 2, 1944, New York, N. Y.

American Society for Metals. Annual convention, October 18–22, 1943, Chicago, Ill.

American Society of Mechanical Engineers. Annual meeting, November 29–December 3, 1943, New York, N. Y.

American Welding Society. 24th annual meeting, week of October 18, 1943, Chicago, Ill.

Electrochemical Society. Biannual convention, October 13–16, 1943, New York, N. Y.

Engineers Council for Professional Development. Annual meeting, October 23, 1943, New York, N. Y.

Exposition of Chemical Industries. December 6, 1943, New York, N. Y.

Illuminating Engineering Society. Special one-day meeting, October 13, 1943, New York, N. Y.

National Electrical Manufacturers Association. October 25–29, 1943, New York, N. Y.

National Metal Congress and War Display. October 18–22, 1943, Chicago, Ill.

National Safety Congress and Exposition, October 5–7, 1943, Chicago, Ill.

Society of Automotive Engineers. Fuels and lubricants meeting, November 4–5, 1943, Tulsa, Okla.

Society of Chemical Industry. Presidential dinner, October 22, 1943, New York, N. Y.

Society of Motion Picture Engineers. 54th semi-annual technical conference, October 18–22, 1943, Hollywood, Calif.

Society of Naval Architects and Marine Engineers. 50th anniversary and annual meeting, November 10–13, 1943, New York, N. Y.

U. S. Power-Capacity Increase Announced for 1945

Seven specific projects which will add approximately 500,000 kw to the nation's power capacity for 1945 operation were announced recently by J. A. Krug, director of the Office of War Utilities of the War Production Board.

The program, representing the smallest annual increase since the beginning of the war, will consist largely of additions to present plants as follows:

1. Installation of unit 7 at Grand Coulee, adding 108,000 kw rated capacity to this development.

2. Addition of approximately 100,000 kw in existing hydroelectric plants of the Tennessee Valley Authority system, to be completed sometime in 1945.

3. A 20,000-kw steam-power addition to the San Antonio, Tex., municipal plant, to be completed late in 1944.

4. An additional boiler for the Jacksonville, Fla., municipal plant which will increase capacity 15,000 kw. This also will be completed in 1944.

5. An additional unit of 20,000 kw for the Evansville, Ind., steam plant of the Southern Indiana Gas and Electric Company, scheduled for completion in 1944.

6. A 25,000-kw unit for the St. Petersburg, Fla., steam plant of the Florida Power Corporation.

7. A 20,000-kw steam plant at Pensacola, Fla., to be built by the Gulf Power Company. These latter two are scheduled for completion early in 1945.

In addition to these specific projects, 200,000 kw new capacity will be needed for industrial sections of the country dependent on steam power, where 1944 loads are expected to run close to capacity. Sizes of the individual units and the exact locations for them have not been determined as yet.

Southwest Valleys Power Administration Created

The Southwest Valleys Power Administration, created by President Roosevelt to handle the power of three Federal hydroelectric projects in the southwestern section of the United States, became effective September 1, 1943. Douglas Wright, formerly special representative of Federal Works Administrator at the Pensacola project, was named acting administrator of the new agency.

By executive order, Denison Dam, between Oklahoma and Texas, Pensacola Dam, in eastern Oklahoma, and Norfolk Dam, in northern Arkansas, were placed under the Department of the Interior in so far as the distribution and sale of power are concerned. The President also set up an order of priorities for the sale of power, and placed the co-operatives in the second group. Since the Administration was authorized to deliver power over existing facilities, the systems are now virtually common carriers.

New Mathematics Quarterly Issued at Brown University

The second number of a *Quarterly of Applied Mathematics* which is being published under the sponsorship of Brown University, Providence, R. I., has been issued. A board of editors drawn up on a national scale has been appointed, consisting of: H. L. Dryden, National Bureau of Standards, Washington, D. C.; T. C. Fry, Bell Telephone Laboratories, Inc., New York, N. Y.; Theodore von Karman, California Institute of Technology, Pasadena; J. M. Lessells, Massachusetts Institute of Technology, Cambridge; I. S. Sokolnikoff, University of Wisconsin, Madison; J. L. Synge, Ohio State University, Columbus; W. Prager, Brown University, who has been appointed managing editor.

The editors have expressed the hope that the quarterly which was founded, "to meet the needs of certain mathematicians and engineers whose interests extend beyond the accepted boundaries of their respective groups," will cut across the lines of demarcation dividing science into compartments. To fulfil this purpose, papers in applied mathematics of an advanced character are sought. The editors plan to use the common ground of mathematics and engineering as a starting point from which the scope of the quarterly's subject matter will grow.

Mentioned as falling within the legitimate subject matter of acceptable articles are: fluid mechanics, elasticity, plasticity, thermodynamics, classical mechanics, and the particularly fruitful field of electrical engineering. The ideal contribution is defined as one employing advanced and general mathematical methods which lead speedily to results in close agreement with experiment.

The subscription price for the seven by ten inch quarterly is $6.00 per year; single copies $2.00. Subscriptions and orders for single copies may be addressed to: Quarterly of Applied Mathematics, 450 Ahaaip Street, Menasha, Wis., or to Brown University.

New Fire-Protection Policy Adopted by WPB

A new fire-protection policy for safeguarding the nation's most essential resources was adopted recently by the War Production Board. In general, it provides that the materials, components, facilities, and man power required for fire-protective equipment be made available in so far as is compatible with other essential needs and with the objective of securing maximum protection with minimum use of critical materials. Only those resources assigned A ratings by the Resources Protection Board will be provided with fire-extinguishing equipment; other resources will require specific approval by that board.

At the same time the WPB announced the creation of a fire protection committee, headed by Harlow Lewis, chief of the materials control branch of the project division, to which all applications for fire-extinguishing equipment involving construction will be directed. Only applications involving construction, such as sprinkler systems, hydrant and hose systems, and stand-pipe systems will be considered. All other priority applications for fire-extinguishing equipment will be processed by the safety and technical equipment division.

New Photometric Units Adopted in Germany

Before the war interrupted normal international relations, plans had been made to introduce throughout the world on January 1, 1941, a "new" system of photometric units replacing both the international and Hefner systems. An article by Doctor W. Geiss of the Philips Lamp Works, Eindhoven, Holland, in the *Bulletin of the Swiss Association of Electrical Engineers*, volume 33, 1942, pages 395–96, states that the formal change to the new system of units was made in Germany on the date previously set, although the practical transfer still

involved some difficulties. Since factors for converting values from the Hefner system to the new one were not published until 1942, some doubt remains as to the extent of use of the new units in actual practice.

The change of units in practical use involves a fundamental difficulty which has delayed the adoption of any one system. This is that the establishment of a basic unit for light of one color is only a partial solution of the problem. There must also be a uniform method of passing from that color to others, which must be chosen arbitrarily, since there is no ground for saying that any one method is correct. The two systems of units hitherto in use have differed not only in the magnitude of the basic unit but also in the relation between lights of different colors.

The principles of the new system which were accepted internationally in 1937, are:

1. To establish a basic unit by taking the brightness of a black-body radiator at the temperature of freezing platinum as 60 candles per square centimeter.

2. To pass from one color of light to others by use of the standard spectral luminosity factors that were originally established by the American Illuminating Engineering Society and have since been accepted internationally.

It was necessary, however, to have practical working standard lamps of various types calibrated according to this new system. In order to make sure that all countries would have concordant standards, lamps of several types were calibrated by the principal national laboratories and compared. This work was to have been finished early in 1939 so that the new units could be put into use January 1, 1940, but it was delayed, because questions were raised regarding the validity of the luminosity factors. These were not settled until the International Commission on Illumination met in June 1939. Plans were then made to complete the comparisons of standard lamps and to introduce the new system in 1941.

The outbreak of the war naturally prevented meetings of the authoritative international bodies dealing with weights and measures. Consequently, no general adjustment of units has been made. The changes in the countries using the present international system will be relatively small, but they will be slightly different in the various countries and for various types of lamps. In the United States likewise, the changes in ratings assigned to types of lamps in practical use will be small, but it has not seemed desirable to introduce the new units until that step can be taken simultaneously in other countries.

Ratios to be used in conversion from Hefner units to the "new" system were published in 1942 by the German Illuminating Engineering Society in *Das Licht*, volume 12, page 35. In 1928 the International Commission on Illumination set up provisionally a similar set of factors as representing the relation between Hefner and international candles for various types of filament lamps. From comparison of these two series of conversion factors, the item cited concludes that the transition from international to new units can be made in Switzerland without any changes in established specifications for lamps or in recommendations regarding illumination.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Nikola Tesla's Achievements in the Electrical Art

To the Editor:

The Tesla article published in *Electrical Engineering*, August 1943, pages 351–357, impels me to send some personal reminiscences which may be of some slight value.

It is a fact not generally known that Tesla offered his patents to The Mather Electrical Company at Manchester, Conn., before going to Westinghouse. When Professor Anthony left Cornell University he went to The Mather Company as chief engineer, and soon after that Tesla came from New York with his motors—several stators and a number of rotors wound in different ways—all two-phase fractional-horsepower. Arrangements had been made for two-phase supply, and the tests covered considerable time.

The Mather Company was controlled largely by the Cheney Silk Industries, and, as they were not disposed to furnish funds necessary to develop the new system, the Tesla offer was rejected, and the honor that might have been Manchester's went to Pittsburgh.

There was a mixture of droll geniality in the Tesla character discernible at times. He told certain hearers that he would place two wires together in powder, and while current was flowing, would separate them without exploding the powder. This seemed a rather remarkable feat, and after some discussion he was asked for a demonstration. He replied that he would use tooth powder. All discussion ceased.

The Mather Company manufactured motors of small capacity, and they were sent out with rather elaborate printed instructions in regard to brush adjustment and general care. Tesla looked over a copy and said: "I will make a motor that may be given to a . . . man with the instructions, 'Here, you . . . fool, grease the bearings.'" This was, indeed, a considerable simplification.

While watching the testing of a motor on the Anthony–Bracket dynamometer then in use he said, "I will make a motor of a thousand horsepower." The largest motor made in Manchester at that time was 40 horsepower, and the sale of a motor of that size was a gala event. His statement seemed like a long look ahead, but it was not many years before a Tesla motor of that capacity was running in Hartford.

FREDERICK G. STRONG (F '13)
(Retired, Wethersfield, Conn.)

Polyphase Armature Windings

To the Editor:

In laying out the connections for a balanced three-phase armature winding with a fractional number of slots per pole per phase, it is sometimes taken for granted that the voltage vectors in the diagram of the winding are separated by equal angles in all cases. It is possible, of course, to take any numerical case and, by finding the angle for each vector, to show that the separations are equal for that case. However, the following general proof may be desirable

Let the number of slots be s and the number of poles be p. Reduce the fraction s/p to r/q by canceling out factors as much as possible; that is, r and q contain no common factor. The letter r then denotes the number of slots in a repeatable section and q the number of poles in a section. For a balanced three-phase winding, r must be divisible by 3.

Since a lower coil side is always at the same phase angle from an upper coil side in the same coil, with the usual diamond coils which are all alike, the voltages developed in all the upper coil sides may be computed first. The voltages developed in the lower coil sides will be the same in magnitude and in relation to each other and may be added on vectorially—in one step—using the usual coil pitch factor.

The position angles in electrical radians, or the phase angles of the fundamental electromotive forces of the upper coil sides of the first few slots of a repeatable section are

$$0, \frac{q\pi}{r}, \frac{2q\pi}{r}, \frac{3q\pi}{r}, \ldots$$

since r slots correspond to q poles, and the angle of the entire section of q poles is $q\pi$. When these angles become greater than π, then π or a multiple of π is to be subtracted, so that the angle is measured on the nearest pole and is always less than π.

An angle $(mq/r-1)\pi$ cannot be the same as any of the preceding angles, since $mq-r-m_1q$ or $(m-m_1)q-r$, cannot equal 0, as q is not a factor of r. Similarly for

the nth pole $(mq/r-n)\pi$ cannot be the same as any of the preceding angles, since $mq-nr-(m_1q-n_1r)$, or $(m-m_1)q-(n-n_1)r$, cannot equal 0, because, if it did, r/q would equal $(m-m_1)/(n-n_1)$. But $m-m_1$ is an integer less than r, and $n-n_1$ is an integer less than q. Therefore the fraction r/q would have been reduced to a smaller numerator and denominator, which was stated to be not possible when r and q were defined.

Since every angle is different from all the preceding angles, no two are alike. Therefore there are r different angles all less than π, for the r slots of the section. They are all of the form

$$\left(\frac{mq-nr}{r}\right)\pi$$

all the letters except π being integers. There are r different numerators, all less than r and all integers, including 0, and so they must be

$$0, 1, 2, 3, \ldots (r-1)$$

That is, the vector diagram for the fundamental voltage of the slots is a fan with the vectors equally spaced at the angle π/r, when the vectors are drawn from one point.

One third of this fan, covering 60 electrical degrees, may be taken for each of the three phases. This will be the best arrangement, as it will give the largest resultant voltage. Any other arrangement, even though it might give a balanced winding, would involve using one or more vectors more than 30 degrees from the resultant instead of less than 30 degrees from it.

HERBERT B. DWIGHT (F '26)

(Professor of electrical machinery, Massachusetts Institute of Technology, Cambridge, Mass.)

Testing Motors for Merchant Marine

This completed powerful propulsion motor, being tested at the Pittsfield (Mass.) Works of the General Electric Company, is one of many under construction for a fleet of vessels ordered by the United States Maritime Commission. The motors are manufactured in shops once devoted mainly to production of large power transformers

NEW BOOKS • • •

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Practical Physics. (Industrial Series.) By M. W. White, K. V. Manning, R. L. Weber, and R. O. Cornett. Prepared under the direction of the division of arts and science extension, Pennsylvania State College. McGraw-Hill Book Company, New York, N. Y., and London, England, 1943. 365 pages, illustrations, etc., 9½ by 6 inches, cloth, $2.50. (ESL.)

This elementary, practical, and abbreviated text in introductory general physics is designed to meet a specific need created by the pressure of wartime conditions. Primary emphasis is placed upon the basic principles of those portions of physics that are of immediate use in war industry, technical work, and the armed services. Simple illustrative experiments are included.

Synthetic Resins and Allied Plastics. By various authors, edited by R. S. Morrell. 2nd edition. Oxford University Press, New York, N. Y.; Humphrey Milford, London, England, 1943. 580 pages, illustrations, etc., 9 by 5½ inches, cloth, $12. (ESL.)

In the general introduction a summary is given of the chemical and physical properties of the most important classes of synthetic resins and plastics. Succeeding chapters deal with the technology of the preparation and use of these various classes of synthetics, with considerable space devoted to the problems of resinification. The last chapter discusses methods of identifying and testing synthetic resins and other raw materials of plastics. Chapter bibliographies are included.

Fundamentals of Electricity. By W. H. Johnson and L. V. Newkirk. The Macmillan Company, New York, N. Y., 1943. 212 pages, illustrations, etc., 11½ by 8 inches, linen, $2. (ESL.)

This preinduction course in electricity is prepared in accordance with United States Army specifications for skilled training. It covers basic magnetic and electrical theory; describes the construction and operation of typical electrical apparatus, including storage batteries, meters, motors, and rectifiers; and illustrates all topics by means of effective photographs and diagrams. Many practical laboratory experiments are included.

Alternating Currents for Technical Students. By C. C. Bishop. 2nd edition. D. Van Nostrand Company, New York, N. Y., 1943. 424 pages, illustrations, etc., 8 by 5½ inches, cloth, $2.50. (ESL.)

The purpose of the book is to explain graphically and with simple mathematics the fundamental principles of a-c theory, circuits, and apparatus. In this second edition, some of the material has been rearranged and expanded to conform with changes in recent years. In particular, a chapter on complex quantities has been added, and their application to circuit problems is shown and compared with the step-by-step method of solution.

Refrigerating Data Book and Catalog, 5th edition. American Society of Refrigerating Engineers, New York, N. Y., 1942. 518 pages, catalog section, 160 pages, illustrations, etc., 9½ by 6½ inches, fabrikoid, $4. in United States, $4.50 other countries. (ESL.)

This edition of this well-known reference

New Automatic Helium-Shielded Arc Welder

Under a shield of helium gas which affords precise control of concentrated heat and protects the molten metal from the oxidizing effect of oxygen in the air, this newly designed automatic arc-welding equipment, in operation at General Electric Company, Schenectady, N. Y., makes smooth clean welds at rates up to 40 inches per minute on 1/8-inch stock. The electronic control panel at the right controls arc length even while the arc climbs and descends inclines; the slanting tube at the lower left directs filler wire into the arc at the correct angle and at a predetermined rate of speed; and the tungsten electrode and gas nozzle are carried by the rod perpendicular to the work. All operations are controlled at upper left panel

book has been revised thoroughly and reset in more readable form. It is substantially a revision of the 1939 edition, devoted chiefly to the basic principles and data of refrigeration and to the major kinds of refrigerating and air-conditioning machinery.

Ferromagnetism. By J. R. Ashworth. Taylor and Francis, London, E.C.4, England, 1943 printing, first published in 1938. 97 pages, charts, etc., 9 by 5½ inches, cloth, 7s. 6d. (ESL.)

The contents of this book are confined closely to the development of a ferromagnetic equation based on the analogy of the fluid laws. This development depends to a considerable extent upon the application of van der Waals' equation of state to magnetism. The material in the book is a revised and co-ordinated presentation of the results of experiments published over a long period in various English scientific journals.

Dynamical Analogies. By H. F. Olson. D. Van Nostrand Company, New York, N. Y., 1943. 196 pages, diagrams, etc., 9 by 5½ inches, cloth, $2.75. (ESL.)

This book deals with the analogies between electrical, mechanical rectilineal, mechanical rotational, and acoustical systems. By means of analogies, the knowledge of electric circuits may be applied to the solution of problems in mechanical and acoustical systems. The subject matter is developed in stages from the simple element to complex arrangements of multielement systems. The text assumes a familiarity with the elements of a-c theory and physics.

Small Arms Manual. By J. A. Barlow and R. E. W. Johnson. Revised edition. John Murray, Albemarle Street, London W., England, 1942. 232 pages, diagrams, etc., 5½ by 4 inches, flexible, $1. (ESL.)

The major part of this manual is devoted to detailed instructions for the operation, taking down, and assembling of various types of small arms, chiefly of British manufacture. The classes covered are rifles, light machine guns, machine carbines, revolvers, and automatic pistols. Ammunition and special features are noted, and there is brief information on the functions in battle of these types of weapons.

Ceramic Trade Directory, 1943. 6th edition. Ceramics Publishing Company, Newark, N. J. 300 pages, illustrations, etc., 7 by 4½ inches, fabrikoid, $6. (ESL.)

Informative data are presented concerning companies engaged in the ceramic industries, classified with respect to character of ware manufactured. There are also a complete geographical index to companies and plants and an alphabetical index of company officials. A buyers' guide to materials and equipment, a list of technical and trade associations, and a list of trade names of ceramic wares are included.

The City, Its Growth, Its Decay, Its Future. By E. Saarinen. Reinhold Publishing Corporation, New York, N. Y., 1943. 380 pages, illustrations, etc., 9½ by 6 inches, cloth, $3.50. (ESL.)

A noted architect here presents his views on city planning in the form of an analytic study of the urban community. How this community during historic time has been born, has grown, has aged, and then decayed are described, and why all this happened is shown. The remedies are considered. The subject is presented from the layman's viewpoint, and the book will interest many who are not professionally concerned.

Electronic Control of Resistance Welding. By G. M. Chute. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1943. 389 pages, illustrations, etc., 9½ by 6 inches, cloth, $4. (ESL.)

This textbook is based on experience in preparing men without technical training to keep resistance welding equipment in service. Electron tubes and their circuits, as used to control welders, are described in detail with diagrams of the circuits. Synchronous timers and stored-energy controls are explained. The text is simple and practical.

PAMPHLETS • • •

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Preliminary Statement of "The Gray Plan" for Postwar Re-employment. Carl A. Gray. The Grenby Manufacturing Company, Plainville, Conn., 1943. 40 pages, no charge.

Handbook of Production Controls. Research Institute of America, 292 Madison Avenue, New York 17, N. Y., 146 pages, $2.00.

Plan Postwar Jobs—Now. Committee for Economic Development, Suite 3311, Department of Commerce Building, Washington 25, D. C., 32 pages.

Accident Facts, 1943 Edition. National Safety Council, Inc., 20 North Wacker Drive, Chicago 6, Ill., 96 pages, 50 cents per copy for orders of one to ten copies. Reductions on larger orders.

Testimony to the Future. National Association of Manufacturers, 14 West 49th Street, New York 20, N. Y., 20 pages.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Any discussion of these papers will appear in the December 1943 Supplement to Electrical Engineering—Transactions Section

Interim Report on Overloading Current-Limiting Reactors

AIEE TRANSFORMER SUBCOMMITTEE

Preface: The present war emergency requires that the maximum use be made of existing equipment and systems and that a minimum of critical material be used for new equipment.

This publication, as well as other guides and reports in this series, has been prepared for the information of users during the war emergency. Upon termination of the war emergency, they will be reconsidered by the Standards committee and the committees that prepared them, and will be approved, revised for normal use, or rescinded.

This procedure is being followed in preference to the preparation of special emergency Standards which might involve redesigning and drastic changes in manufacturing practices. These guides will accomplish the maximum conservation of critical materials, since they provide for the maximum use of existing equipment and systems, as well as new equipment, without changing the fundamental basis on which the present Standards have been prepared.

THIS report presents a general guide for loading current-limiting reactors above rating where specific design and operating data suitable to determine such loading are not available. It should be used in conjunction with the "Interim Report on Guides for Overloading Transformers and Voltage Regulators," presented on June 22, 1942, by the AIEE transformer subcommittee at the summer convention, which appeared in the September 1942 issue of ELECTRICAL ENGINEERING, as many data included there are not repeated in this report.

Temperature Limits

The present Standards for reactors provide that the temperature rise of the hottest spot of the windings shall not exceed 65 degrees centigrade for oil-insulated reactors and for dry-type reactors with Class *A* insulation or 90 degrees centigrade for dry-type reactors with Class *B* insulation, and that they shall be suitable for continuous operation at rated load, provided that the ambient temperature does not exceed 40 degrees centigrade and the daily average ambient temperature does not exceed 30 degrees centigrade.

This means that the total temperature of the hottest spot of the windings should not exceed a daily average of 95 degrees centigrade for oil-insulated reactors and dry-type reactors with Class *A* insulation or a daily average of 120 degrees centigrade for dry-type reactors with Class *B* insulation.

Reactors built to the present standards are often installed in compartments with restricted ventilation where the temperature of the reactor may be 10 to 15 degrees centigrade higher than when installed in the open. Under such conditions, dry-type reactors with Class *A* insulation are applied and operated under conditions that may result in an average daily hot-spot temperature of 105 degrees centigrade, and dry-type reactors with Class *B* insulation are applied and operated under conditions that may result in an average daily hot-spot temperature of 135 degrees centigrade.

Because of the aforementioned experience, it is undoubtedly safe to operate at these increased temperatures during this period. In order to prevent confusion in the case of reactors not enclosed in compartments, the ambient temperature is intended to mean the temperature of the air at a sufficient distance from the reactor not affected directly by the losses of the reactor. Likewise, in the case of reactors enclosed in compartments, it is not intended to refer to the temperature within the compartment but to the air surrounding the compartment.

Effect of Ambient Temperature on Continuous Loading for Normal Life Expectancy

The effect of ambient temperature on the loading of reactors is as follows:

If the daily average ambient temperature is below the reference of 30 degrees centigrade ambient, the loading may be increased, and, if the daily average ambient is above the reference ambient, the loading should be decreased as follows:

	Correction Per Cent Per Degree Centigrade Difference From the Reference
For oil-immersed reactors	1.0
For dry-type Class *A* reactors	0.75
For dry-type Class *B* reactors	0.5

Effect of Load Factor on Loading for Normal Life Expectancy

LOAD FACTOR

For daily load factors below 100 per cent, the loading may be increased 0.3 per cent for each per cent that the load factor is below 100 per cent, with normal life expectancy. Corrections in greater detail, based on an actual load curve, are not usually justified for normal loading. In no case should the overload permitted by this factor exceed 15 per cent, corresponding to 50 per cent daily load factor.

Paper 43-109, recommended by the AIEE committee on electrical machinery for presentation at the AIEE national technical meeting, Cleveland, Ohio, June 21–25, 1943. Manuscript submitted May 21, 1943; made available for printing June 6, 1943.

Personnel of the transformer subcommittee: M. S. Oldacre, *chairman;* F. S. Brown, E. S. Bundy represented by R. T. Henry, J. E. Clem, I. W. Gross, V. M. Montsinger, J. R. North, W. C. Sealey, F. J. Vogel, C. F. Wagner.

This interim report was prepared by the AIEE transformer subcommittee of the committee on electrical machinery for the purpose of making essential information immediately available to war industries, thus furthering the conservation of valuable material for the war emergency. It is educational and in no way mandatory. It is not intended as a "Standard," and has not been formally approved by the Standards committee nor the board of directors.

Emergency Short-Time Loading for Normal Life Expectancy

The following paragraph and Tables I and II indicate the short-time loads that can be carried without affecting normal life expectancy in 30 degrees centigrade daily average ambient.

Oil-Immersed Reactors

Oil-immersed reactors may be overloaded under emergency conditions in accordance with the curves given in American Standard *C57.3*, "Guides for Operation of Oil-Immersed Transformers."

Emergency Loading With Moderate Sacrifice of Life Expectancy

Tables III, IV, and V indicate the emergency overloads that can be carried with moderate sacrifice of life, probably not exceeding one per cent for each application, in 30 degrees centigrade daily average ambient.

Use of Other Corrections With Overload Values Given in Tables

Care should be taken that the percentage change from each of the various causes be based on the reactor current rating and not on the increased loading resulting from any of the other corrections.

The effects of the various following factors may be added directly:

For normal operation with normal life expectancy the effects of load factor, ambient temperature, and supplemental cooling may all be added in determining the load capability.

For short-time emergency operation with either normal life expectancy or moderate sacrifice of life, the effect of the actual ambient temperature during the emergency and of supplemental cooling may be added to the value for the emergency operation.

This method of adding corrections is not rigorously correct, but it is sufficiently correct for practical purposes and is simple to apply.

Table I. Dry-Type Class *A* (Enclosed in Compartment)*

Duration of Load (Hours)	Hot-Spot Temperature (Degrees Centigrade)	Times Rated Load Current: Following Full Load	Following Three-Quarter Load	Following No Load
1	120	1.21	1.40	1.65
2	115	1.10	1.17	1.27
4	110	1.04	1.06	1.08

* See footnote for Table V.

Table II. Dry-Type Class *B* (Enclosed in Compartment)*

Duration of Load (Hours)	Hot-Spot Temperature (Degrees Centigrade)	Times Rated Load Current: Following Full Load	Following Three-Quarter Load	Following No Load
1	150	1.15	1.35	1.60
2	145	1.07	1.15	1.25
4	140	1.03	1.05	1.07

* See footnote for Table V.

Supplemental Cooling

The design of dry-type reactors is such that forced-air cooling may be readily applied, provided sufficient space is available for the cooling equipment. For best results, the flow of air should pass over all the windings of the reactor. The permissible load can be increased in some cases as much as 30 per cent for the same temperature rise. The efficiency of forced-air cooling varies, and each application should be carefully investigated to determine the permissible increased loading.

Table III. Oil-Immersed Reactors

Duration of Load (Hours)	Hot-Spot Temperature (Degrees Centigrade)	Times Rated Load Current: Following Full Load	Following No Load
1	137	1.9	2.00
2	130	1.65	2.00
4	125	1.45	1.7
8	120	1.30	1.4
24	110	1.15	1.15

Table IV. Dry-Type Class *A* (Enclosed in Compartment)*

Duration of Load (Hours)	Hot-Spot Temperature (Degrees Centigrade)	Times Rated Load Current: Following Full Load	Following Three-Quarter Load	Following No Load
1	137	1.40	1.60	1.80
2	130	1.25	1.30	1.40
4	125	1.15	1.16	1.18
8	120	1.10	1.10	1.10

* See footnote for Table V.

Table V. Dry-Type Class *B* (Enclosed in Compartment)*

Duration of Load (Hours)	Hot-Spot Temperature (Degrees Centigrade)	Times Rated Load Current: Following Full Load	Following Three-Quarter Load	Following No Load
1	160	1.25	1.45	1.70
2	155	1.15	1.20	1.3
4	150	1.08	1.10	1.12
8	145	1.05	1.05	1.05

* Dry-type reactors with both Class *A* and Class *B* insulation installed in the open with three or more feet of head room will carry 7.5 per cent more load than when enclosed in compartments. In all cases where these conditions are not met the extra overload should be obtained from the manufacturer.

Cautions and Limitations

It must be recognized that overloads should not be applied to current-limiting reactors without a thorough study of the various limitations involved. If reactors are operating at higher than standard temperatures, the permissible duration of short-circuit may be reduced slightly. Among other limitations are: soldered connections, leads, effects of increased magnetic fields on surrounding equipment, as well as the thermal ability of connected equipment.

Before overloading current-limiting reactors to the full extent covered in this report, it is recommended that overload capabilities of the reactor be checked with the manufacturer.

Design Relationships for D-C Generators for Use in Aircraft

S. R. BERGMAN
ASSOCIATE AIEE

Synopsis: The paper sets forth the different operating conditions met with in aircraft generators as compared with standard types of industrial generators. It discusses certain features inherent in applications to aircraft, such as reliability and light weight. Certain requirements in both electrical and mechanical design are imposed by the fact that a plane is flying through varying altitudes resulting in changing atmospheric conditions, such as rarefication, low temperature, and ionization. Other unusual conditions are created from the motion of the plane setting up accelerating forces on the generator, as well as mechanical forces caused by engine vibrations. Because of important features such as commutation, voltage regulation, cooling, driving means, and light weight, special and unusual methods must be employed. In solving these problems the most perfect methods known in the art of building d-c machines must be resorted to, and the paper lays particular stress on the use of compensation.

Main and Accessory Engine-Driven Generators

THERE are two different methods of driving the generator:

1. The generator is driven from the main engine, in which case it is bolted to the engine and splined to a driving gear inside the engine. In some cases the generator is located in the nacelle and driven through a shafting containing two universal joints and a telescoping shaft so as to take up engine vibrations.

2. The generator is directly connected to an accessory engine. In this case the generator must be designed with relatively high efficiency so as to minimize the weight of gasoline consumed by the accessory engine.

The efficiency of main engine-driven generators runs between 70 and 80 per cent for different sizes (see Figure 3), and those driven by accessory engines should have an efficiency of from 85 to 90 per cent. The limitation of the application to accessory engines lies in the fact that they lose power quite rapidly with altitude since no satisfactory supercharger for this type of engine has as yet been developed.

Weights

Low weight is the natural requirement of all parts in airplanes. The weight of d-c generators for aircraft has been reduced to about one tenth of that of industrial generators of the same rating, and this has been accomplished with only a slight suffering in the efficiency. As an example: A d-c airplane generator rated 30 volts, 300 amperes, 4,400/10,000 rpm weighs 45 pounds—that is, five pounds per kilowatt—and has an efficiency of 77 per cent; an industrial-type generator of the same kilowatt rating at 1,750 rpm weighs about 400 pounds—that is, 45 pounds per kilowatt—and has an efficiency of 80 per cent. However, the airplane generator has at full load a temperature rise of 100 degrees centigrade employing an insulation consisting of glass and mica; whereas the industrial type of generator has a 40 degrees centigrade rise, using mainly cotton as a base insulation.

Future developments will be along the lines of better heat-resisting insulation. Varnishes have already been developed which will stand 200 degrees centigrade continuously without deterioration. Taking advantage of these higher temperatures, we may expect a further reduction in weight.

Influence of Atmospheric Conditions

The atmospheric conditions influence the cooling of the generator, affect the wear of the brushes, and because of rarefication and ionization influence insulation and creepages.

In the region in which the engine-driven generator is installed between the rear of the engine and fire wall, the ambient temperature is rather high, varying from 35 degrees centigrade to 65 degrees centigrade, and remains independent of the altitude. Since the density of the air decreases with the altitude, the cooling decreases in all self-ventilated generators. The permissible output is, therefore, reduced with the altitude and at a certain point, usually within the range of the plane, it becomes zero. Therefore, self-cooled engine-driven d-c generators are not advocated. Another type of cooling system consists of scooping the air from the outside of the plane and forcing this air through the generator. Since this cooling air has a very much lower temperature at high altitudes, it compensates for the decreased density. Investigation shows that the permissible output remains constant independent of the altitude. Blast cooling has, therefore, been generally adopted. In Figure 1 is shown how the ventilation is accomplished in a blast-cooled d-c generator.

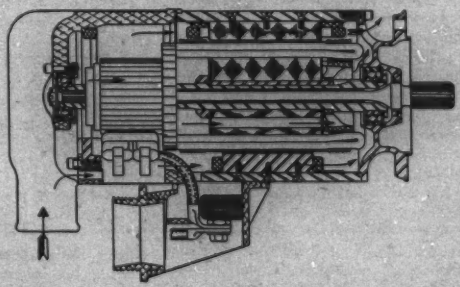

Figure 1. Assembly of d-c aircraft generator showing blast cooling

The influence of the atmospheric conditions at high altitude on the wear of the brushes is a serious one. While considerable progress has been made in the solution of this problem, it is not as yet fully solved. It is a well-known fact that a good commutator which has operated for some time at sea level builds up a glossy film, the surface of which consists mainly of carbon. At high altitudes, ordinary brushes have been found to wear down quite rapidly. Experiments undertaken in altitude chambers have shown this effect is related to the reduced moisture and oxygen content of the air, but special brush types have been found which give longer brush life. It has also been found that a cool commutator

Paper 43-126, recommended by the AIEE committee on air transportation for presentation at the AIEE national technical meeting, Cleveland, Ohio, June 21-25, 1943. Manuscript submitted April 5, 1943; made available for printing May 26, 1943.

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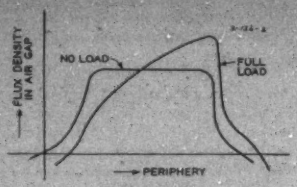

Figure 2. Flux distribution of a noncompensated d-c generator

and brushes are beneficial to brush life. Perfect commutation is important since it contributes to low temperatures. While it is difficult to give any definite rules for the design of commutators and brushes to give satisfactory brush wear, it may be stated that if the temperatures of commutator and brushes are limited to 100 degrees centigrade rise at sea level, and if the current density in the brush contact is also limited to less than 120 amperes per square inch, a reasonable brush life may be expected, provided that proper brushes are used.

The rarefication of the atmosphere at altitude in combination with ionization influences the breakdown voltage of the air. Between small spheres the breakdown voltage is proportional to the air density, for example, at 30,000 feet it is about one third of that at sea level. The ionization within the range of flight is comparatively small, and its influence on the sparkover voltage is probably quite small. However, if an arc is started, then, because of the great mobility of the charged particles, intense ionization will take place, and the arc will extend itself more quickly than at sea level. Therefore, it is quite important that no arcs or sparks are started. This requires three conditions to be fulfilled:

1. The commutation should be perfect.
2. The brush rig should be so designed as to prevent the sudden lifting of the brushes from vibrations.
3. Sufficient creepage distances should be provided for. For example, in a 30-volt generator the creepage distances should be no less than three sixteenths of an inch.

These circumstances must be taken into consideration when the voltage of the d-c system is determined. The 24-volt system has been found to be quite satisfactory. It has also been found that in certain motor generator sets which are used for turret and gun control 60 volts seems to be satisfactory. Engine-driven generators rated 120 volts have been built

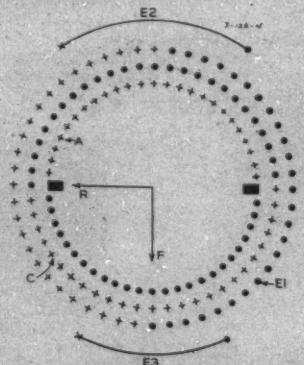

Figure 4. Schematic sketch of compensation and excitation

and mounted in the nacelle of flying boats; however, the ceiling for these ships is comparatively low, probably from 20,000 to 30,000 feet, and further experience will be required to evaluate fully the merits of voltages higher than the 30-volt system.

Vibrations

The vibrations of the engine are very severe, and the magnitude of the forces are not fully known. To guard against failure of the generator, any new design should have an engine test, preferably on the engine for which it has been designed. This run should not be less than 125 hours at different speeds. The engine vibrations are transmitted to the brushes of the generator, tending to throw them off the commutator. To prevent this, spring pressures should be comparatively high, but not so high as to cause excessive brush wear. It has been found that about

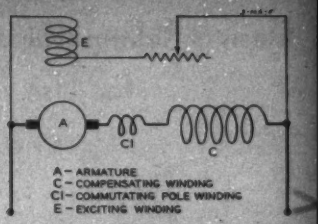

Figure 5. Winding diagram

five pounds per square inch of the brush contact is a good compromise. It is also advantageous to use a large number of small brushes, so that if a few brushes are thrown off, there are others to do the work. The inertia of the brushes should be made as low as possible to minimize these forces.

Another kind of vibration built up by the engine is the torsional vibration transmitted to the shaft. To take care of these vibrations a quill drive is employed (shown in Figure 1). In order to avoid resonance an asbestos packing is used between the inner and outer shafts, which serves as a damping medium. It may be pointed out that this is a nonwearing packing, since it does not slide but depends entirely upon internal molecular friction.

Electrical Characteristics

The electrical design must secure reliability of operation and light weight.

The reliability requires sparkless commutation at all speeds and for short heavy overloads; even short circuits should not be injurious to the commutator or brushes. In Figure 2 is shown a typical flux distribution curve in a noncompensated generator. It may be noted that

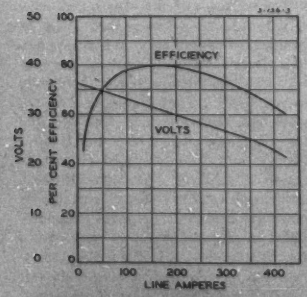

Figure 3. Regulation and efficiency curves of a compensated d-c generator

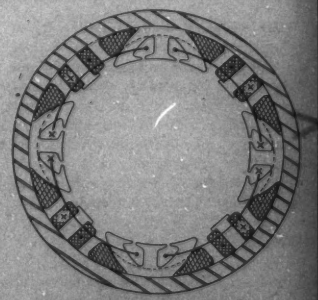

Figure 6. Structure of d-c generator with salient poles and compensation

at load the flux has been distorted in height and also shifted at the same time. This flux distortion is reflected in a similar distortion of the potential around the commutator, resulting in an increased maximum voltage between bars and also a piling up of the voltage toward one of the brushes. Under extreme conditions the maximum volts between bars may be increased from 30 to 40 per cent at full load, and near the brush it will be multiplied several times. Should excessive sparking occur, particularly when the air is rarefied and ionized, an arc may be formed and carried around to the next brush, very likely ruining the generator. This phenomenon is eliminated by the use of compensation, which has for its main object the stopping of flux distortion.

Since the heating is the limiting condition for light weight, an electrical design should be adopted which gives minimum losses. One solution which meets this requirement is the use of compensation, as it eliminates the load losses. Since compensation neutralizes the armature reaction, no field distortion takes place; hence, no extra core loss occurs. Compensation also eliminates sparking and thus does away with extra losses in the brush contacts and in the short-circuited coils. The extra losses in generators without compensation may be considerable, particularly in high-speed machines at weak field. In extreme cases it has been observed to amount to eight points in the efficiency.

Another feature of reliability of the generator is the proper shape of the regulation curve, showing the relationship between amperes load and the terminal voltage. As shown in Figure 3 this curve should be a uniformly drooping line, which is helpful in giving stable operation of the voltage regulator and also contributes to

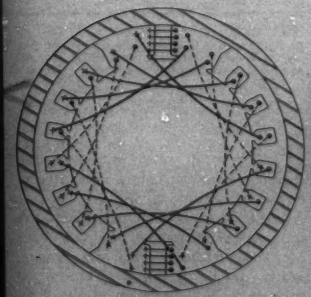

Figure 7. Structure of d-c generator with distributed windings

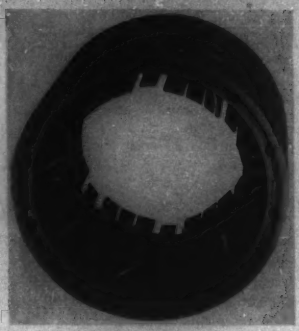

Figure 8. Six-pole field structure of compensated d-c generator

equal current distribution when several generators are operated in parallel, as is the case in multiengined planes. In Figure 3 is shown a typical regulation curve of a compensated generator, showing its uniformly drooping character.

Compensation

The principle of compensation is shown schematically in Figures 4 and 5. Referring to Figures 4, *A* represents the armature winding which may be wound with any of the usual types of windings. Surrounding the armature is a field structure carrying the compensating winding *C*, which is connected in series with the armature, in opposition to it and equally as strong as the armature reaction *R*; thus these two windings constitute a nearly noninductive pair; that is, no flux except a small leakage flux will be produced. In order to commutate, a certain amount of commutating flux is necessary, and this flux is produced by overcompensation located on commutating poles, which for simplicity is not shown in Figure 4.

Figure 9. Complete field of four-pole compensated d-c generator

The field excitation *F* may be applied in two different ways:

1. In concentrated coils *E*2 and *E*3 assembled on salient poles.

2. It may be distributed in a winding *E*1 in which case we arrive at a d-c generator in which both the excitation and the compensation are fully distributed.

In Figure 6 is shown the structure of a d-c generator with salient poles and concentrated excitation. It also shows the compensating winding and the commutating poles with their windings.

In Figure 7 is shown the structure of a d-c generator with both the compensation and excitation distributed. Full drawn lines indicate the compensation, and dotted lines the excitation. It also shows the commutating poles with their windings. When inspecting the winding in Figure 7, it is of interest to observe that these windings are similar to a two-phase winding in a two-phase induction motor, one phase corresponding to the excitation and the other phase corresponding to the compensation. These two windings are

Figure 10. Complete field of an accessory engine-driven d-c generator with fully distributed windings

90 electrical degrees apart in space. It should also be noted that the pitch of these windings is 50 per cent, which secures short end windings and thus reduces losses.

In order to further illustrate the principle of compensation, reference is made to Figure 8, which is a photograph of a six-pole field structure rated 30 volts, 200 amperes, 2,500/5,000 rpm.

Figure 9 shows a photograph of a four-pole structure with four salient poles rated 30 volts, 300 amperes, 4,400/10,000 rpm.

Figure 10 shows a photograph of a complete field with windings and brush holders of an eight-kw accessory engine-driven generator with fully distributed windings

Frequency Modulation for Power-Line Carrier Current

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FREQUENCY modulation is known to most people today as a system of broadcasting that is remarkably free from the effects of interference and is capable of providing high fidelity reception. These advantages have been realized largely by employing frequencies of 40 megacycles and higher which are well above the present broadcast band. A great amount of effort has been devoted to this field, and therefore, frequency modulation has been well analyzed both in theory[1-3] and experiment.[4,5] However, most of the work has been done with systems using a large deviation ratio which is usually defined as the ratio of the carrier deviation from normal to the highest modulating frequency.

This paper presents results of investigations carried on with a frequency-modulated system for power-line communication, employing frequencies below 200 kilocycles and a deviation ratio of one to one. In this way, the same band width as required for amplitude modulation, or *A-M*, can be utilized. The results of the investigation substantiate the work of others[3] and indicate that even with a one-to-one deviation ratio an *F-M* system is less disturbed by interference than a comparable *A-M* system. In addition, when such a system is subjected to the type of noise encountered on some power lines, the difference between *A-M* and *F-M* is still more prominent.

Outline of Theory

Unfortunately frequency modulation is not as widely understood as amplitude modulation. If *F-M* had been introduced and used for a number of years before *A-M*, the reverse would probably have been true. Both *F-M* and *A-M* are descriptive of the manner in which a modulating quantity alters a sine function that represents a carrier frequency. Since a carrier frequency is an alternating quantity having both amplitude and frequency as its principal characteristics, it is possible to operate on either one of these to cause the carrier frequency to carry intelligence.

One effective way to compare two different modulation schemes is by the equations for the modulated signal. The equation for an *A-M* signal is merely a sine function whose amplitude, *A*, is varied in some fashion and is usually expressed as

$$e = A(1 + m \sin \alpha t) \sin \omega t \qquad (1)$$

where

$\omega = 2\pi$ times the carrier frequency
$\alpha = 2\pi$ times the modulating frequency
m = amplitude of the modulating frequency and is one for 100 per cent modulation

This equation can be expanded by trigonometric identities into three separate sine functions

$$e = A \sin \omega t + \frac{mA}{2} \cos (\omega - \alpha)t - \frac{mA}{2} \times \cos (\omega + \alpha)t \qquad (2)$$

which can be used to determine the band width of various type channels.

In a similar manner, the equations for a frequency-modulated signal can be developed. Since this has often been done in the literature,[1,3] the important steps only will be given. The equation for the modulated signal is

$$e = A \sin \left(\omega t + \frac{\Delta\omega}{\alpha} \sin \alpha t \right) \qquad (3)$$

To grasp the significance of this equation, it is only necessary to remember that $\Delta\omega$ is directly proportional to the amplitude of the modulating frequency. As the amplitude of a sine function is varied in equation 1 for an *A-M* signal, the frequency of a sine function is varied in equation 3 for a frequency-modulated signal. This last equation can be expanded by means of identities into

$$\begin{aligned} e = A \Big\{ & J_0\left(\frac{\Delta\omega}{\alpha}\right) \sin \omega t + \\ & J_1\left(\frac{\Delta\omega}{\alpha}\right) [\sin (\omega + \alpha)t - \sin (\omega - \alpha)t] + \\ & J_2\left(\frac{\Delta\omega}{\alpha}\right) [\sin (\omega + 2\alpha)t + \sin (\omega - 2\alpha)t] + \\ & \cdots\cdots\cdots\cdots\cdots\cdots + \\ & J_n\left(\frac{\Delta\omega}{\alpha}\right) [\sin (\omega + n\alpha)t + \\ & \quad (-1)^n \sin (\omega - n\alpha)t] \Big\} \end{aligned} \qquad (4)$$

where $J_n\left(\frac{\Delta\omega}{\alpha}\right)$ is the nth order Bessel function of the first kind.

Therefore, instead of one upper and one lower side band as in equation 2, the possibility of many side bands exist. The magnitude of these side bands are fixed by the Bessel functions $J_0\left(\frac{\Delta\omega}{\alpha}\right)$ to $J_n\left(\frac{\Delta\omega}{\alpha}\right)$. However, if $\frac{\Delta\omega}{\alpha} \leq 1$, only the first two terms are significant, and the values of the Bessel functions of the second to nth order

$$\left[J_2\left(\frac{\Delta\omega}{\alpha}\right) \text{to } J_n\left(\frac{\Delta\omega}{\alpha}\right) \right]$$

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rated 30 volts, eight kw, 4,000 rpm.

Both the salient pole construction and the field using distributed windings are being used for aircraft generators. It has been found that the salient pole structure is the lightest of the two structures by about 10 per cent. Since weight is of paramount importance, the salient pole construction is now given preference. While both methods lead to very good commutation, the distributed windings seem to be the most powerful means of obtaining perfect operation, the reason being that it minimizes the leakage and secures a very clean neutral. As an example of how powerful the combination of a distributed compensation and excitation winding is, the author built a separately excited d-c generator rated 150 kw, 15,000 volts, having an average volts per bar of 90, which at full voltage withstood dead short circuits with only a minor flicker on the commutator.

Large industrial machines which have to meet severe operating conditions have been made for many years with compensation. In this paper it has been proved that small d-c generators of the compensated type can be made in a very compact form with light weight.

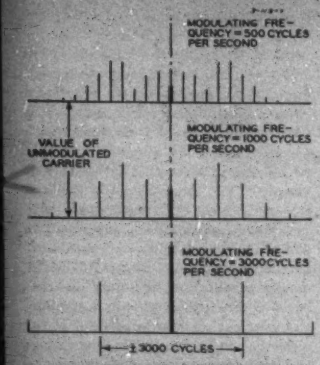
MODULATING FREQUENCY = 500 CYCLES PER SECOND
VALUE OF UNMODULATED CARRIER
MODULATING FREQUENCY = 1000 CYCLES PER SECOND
MODULATING FREQUENCY = 3000 CYCLES PER SECOND
±3000 CYCLES

Figure 1. Chart of the amplitudes of the side bands for three different modulating frequencies when the deviation ratio is one to one

are small. Advantage is taken of this fact in the system discussed in this paper.

Another type of modulation has been used that is closely related to *F-M*, namely, phase modulation or *P-M*.[4] Actually, a frequency shift always changes the rate of phase change and vice versa so that the two functions are dependent on each other. By definition, the two types of modulation, *F-M* and *P-M*, have become associated with the nature of the modulated signal. The equation for a phase-modulated signal, comparable to equation 3, is

$$e = A \sin (\omega t + \phi \sin \alpha t) \qquad (5)$$

This equation can be expanded to be the same as equation 4 except with ϕ substituted for $\frac{\Delta\omega}{\alpha}$. Both of these terms have the dimension of phase angle. For the same intensity of all modulating frequencies, in phase modulation the phase shift is constant, but the frequency shift is proportional to the modulating frequency; while in frequency modulation, the frequency shift is constant for all modulating frequencies and the phase shift is inversely proportional to the modulating frequency. Also, the band width of the former is approximately proportional to the modulating frequency, and the band width of the latter is practically constant. Sufficient swing or modulation cannot be obtained easily with phase modulation, and, since reactance tubes can produce enough frequency modulation at low carrier frequencies, strictly frequency modulation was used in the investigation reported here.

Deviation Ratio

The choice of a one-to-one deviation ratio was influenced principally by the desire to restrict the band width of individual channels to the same space that would be required for a comparable *A-M* channel. This is quite important from the standpoint of any user of power-line carrier. The art has progressed to such a stage that many pieces of auxiliary apparatus have been designed and standardized around amplitude-modulated systems. Therefore, existing apparatus as well as equipment already in production could be used with an *F-M* transmitter and receiver to set up a channel. In other words, if the band-width characteristics of line traps and tuning units are applicable to *F-M*, then there would be no change in the application and installation practices already in use.

Even with a one-to-one deviation ratio, the frequency shift is a large percentage of the carrier as compared to the per cent frequency shift used in present day *F-M* broadcast practice. For instance, a 3,000-cycle shift is six per cent of a carrier frequency of 50 kilocycles, whereas the standard 75-kilocycle shift of a broadcast transmitter at 40 megacycles is only about 0.2 per cent. A greater deviation could be generated at these low frequencies, but the band-width requirements of the receiver and coupling apparatus would be excessive. On the other hand, a smaller deviation would not reduce the required band width proportionately and would only result in a lower degree of modulation.

A better picture of what a one-to-one deviation ratio produces in the way of side bands is given in Figure 1, which shows a chart of the amplitudes of the various side bands for different modulating frequencies. This chart was made up by plotting the amplitudes of the various terms given in equation 4, in which $\Delta\omega$ corresponds to a frequency of 3,000 cycles in all cases. From this diagram it can be seen that the bulk of the side bands are confined to a band width of ±3,000 cycles. Of course, if the utmost in fidelity is desired, some of the side bands extending beyond ±3,000 cycles would have to be transmitted and received. Actually, if all the side bands outside of the ±3,000 cycle band were eliminated, only about four per cent of the total energy in the modulated wave would be lost. This would cause a small amplitude modulation of the carrier to appear, but the limiter in the receiver restores the carrier to a constant amplitude. However, the distortion resulting from eliminating the higher side bands is small compared to the total distortion in any *A-M* carrier channel.

Noise Considerations

Noise reduction by means of frequency modulation has been the largest factor in promoting broadcast *F-M*. Interference to the reception of a desired signal may come from many sources and be of various types. In space radio, the most uncontrollable interference is that which takes the form of modulated frequencies in the band accepted by the receiver. The energy in these frequencies is usually uniformly distributed over the band of any channel and is often termed external random noise. With varying magnitudes of this type noise, *F-M* has the characteristic of keeping the interference well rejected until the magnitude of the noise bears a certain ratio with respect to the desired signal. Then the noise is accepted, and the desired signal is rejected. In wide-swing or large-deviation *F-M* this threshold is quite abrupt and occurs when the signal-to-noise ratio becomes about two. It has been demonstrated[3] that in

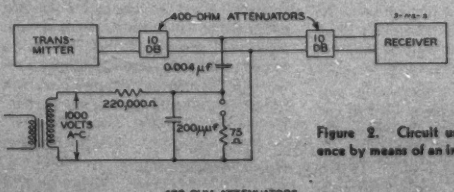

Figure 2. Circuit used to produce interference by means of an intermittent arcing air gap

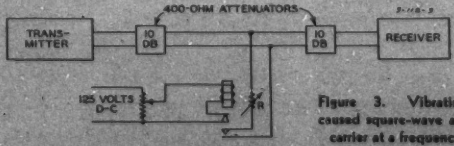

Figure 3. Vibrating-relay circuit which caused square-wave amplitude modulation of carrier at a frequency of about 100 cycles

a small-deviation system, this threshold is not as abrupt and occurs at a lower signal-to-noise ratio. Therefore, it develops that a small-deviation system can deliver usable intelligence from a signal whose signal-to-noise ratio is less than two. This is a definite advantage when the primary function of a service is to get intelligence from one point to another.

There always exists on power lines a fairly high level of random noise caused by corona and arcs of various types acting as sources of amplitude-modulated radio frequencies. In these cases more transmitter power helps in improving the signal-to-noise ratio. Noise of this nature when added to the desired carrier causes a complex type of amplitude variation and phase shift. This produces a signal which is similar to a carrier and a single side band. It is possible for the limiter in an *F-M* receiver to remove the amplitude modulation, but of course it is impossible to eliminate the phase shift. Therefore, it is this phase shift that is the source of noise for an *F-M* channel. It is possible in an *A-M* system for noise to cause a 100 per cent modulation of the carrier, and this is also the limit to the degree of modulation by the desired signal. In frequency modulation it is impossible for noise to cause a phase shift of more than about one radian, but it is possible for the desired signal to cause a much greater phase shift. The phase shift is one radian for the highest value of α when a one-to-one deviation ratio is used. This phase shift becomes greater as α decreases and is the reason for more noise interference present at the higher modulating frequencies. By assuming a random-type noise, the noise reduction theoretically possible by means of *F-M* over *A-M* is six decibels. This is computed from the fact that noise in *A-M* is the same over the audio spectrum while in *F-M* the noise is zero at zero audio frequency and increases linearly to the same value as in *A-M* at the highest audio frequency. Hence, when the noise is integrated over the audio range, it is just half as great in *F-M* as in *A-M*.

Random noise may not be the only type of interference encountered in carrier current or any system where metallic circuits of one kind or another are used for the medium of transmission. In fact, another type of interference, apparently caused by corona, has also been observed on power lines. The carrier in traversing the power line becomes amplitude modulated with noise, and for lack of a better name this phenomenon has been called "corona modulation." The modulation is apparently a result of corona producing an impedance change to the flow of the carrier-current signal. If only this type of noise is present, an increase in transmitter power to surmount the noise does not help because the per cent modulation from the noise stays the same. This modulation is a function of the total attenuation between the transmitter and the receiver and the amount of corona present on the lines. A simple experiment that can be performed to detect this type of noise is to listen to a signal in a carrier receiver with no automatic volume control in operation. When the transmitter is turned off, this type of noise will decrease or completely disappear, indicating that it comes in as modulation of the carrier signal. In this case, the noise is carried by symmetrical side bands about the carrier as represented by the last two terms of equation 2. However, when this type of noise is fed into an *F-M* receiver which contains a balanced discriminator, these side bands are balanced out, since a discriminator is a slope filter whose output is proportional to the frequency deviation from normal. Because an *A-M* signal has amplitude variations but no phase or frequency variations, the output of the discriminator in this case would be zero. Herein is the outstanding advantage of frequency modulation for power-line carrier because it provides the only real solution to corona-modulation noise.

In an effort to improve the discrimination against interference in an *F-M* system still further, advantage may be taken of the energy versus frequency characteristic of the voice.[11] This characteristic indicates that the bulk of the energy in voice exists in the low audio frequencies. Therefore, it is possible to pre-emphasize the higher audio frequencies in the transmitter without exceeding the modulation capabilities of the transmitter. This, of course, makes it necessary to use a de-emphasis circuit in the receiver. Then the scheme is in effect a combination of phase modulation and frequency modulation. It provides a means to get the greatest frequency shift for any modulating frequency without exceeding the band width of any particular channel.

Noise Measurements

With these known facts, a preliminary setup was made in the laboratory consisting of one transmitter and one receiver. The functioning of various circuits was checked, as well as the characteristics of *F-M* when noise was present. These initial results were so promising that a complete communication channel was later set up in the laboratory which involved two transmitters and two receivers and some auxiliary equipment with which more elaborate measurements were made. After considerable development work, a third group of samples was built which embodied all of the improvements and circuit designs worked out in the previous samples. The final samples involved commonly used *F-M* circuits such as a pre-emphasized frequency modulator, a modulation limiter, and a class *C* amplifier in the transmitter; with a radio-frequency amplifier, a limiter, a discriminator, a de-emphasized audio amplifier and a carrier-off noise suppressor in the receiver. Naturally, certain modulations and improvements were made in order to adapt these *F-M* circuits to low-frequency operation.

Extensive tests were made with the samples, of which the noise-reduction measurements were the most interesting. Various schemes were used to produce noise, but the two that proved most acceptable are shown in Figures 2 and 3. The circuit shown in Figure 2 introduced a type of noise which was principally characterized by an arc as a source of radio-frequency energy. The circuit in Figure 3 amplitude-modulated the carrier with a square wave at a rate of about 100 cycles so that several simultaneous noise side bands were produced. Measurements were made to indicate differences between an *F-M* channel and *A-M* channel having the same transmitter power, band width, audio characteristic and attenuation between transmitter and receiver. These measurements were made after both systems were set up in such a way that a 500-cycle modulating frequency produced the same output from both receivers and caused 100 per cent modulation of the *A-M* transmitter and a deviation of 3,000 cycles in the *F-M* transmitter. This particular audio frequency was used because it was just below the point in frequency where the pre-emphasis and de-emphasis circuits began to function. Table I gives the amount the noise level in *F-M* was found below the noise level in *A-M* in decibels. The results in Table I are an average of several measurements with each of the samples mentioned.

Table I

Type of Noise	Unemphasized F-M	Pre-emphasized F-M
Figure 2	11	16 to 19
Figure 3	19	23 to 25

The results show considerably more noise reduction than theory predicted. The theory is based on the assumption that the noise is random, while circuits used here did not necessarily produce random noise. It is felt that the noise encountered on power lines is similar to some combination of the two types of noise employed in these tests. It may be all of one type or any combination of the two. The noise reduction is greater than expected, principally since the bulk of the energy in the noise is in the lower audio frequencies.

Based on these noise measurements made with the arc-noise generator in Figure 2, which utilizes the less favorable type of noise, it would take the following transmitter powers to give the same signal-to-noise ratio in a receiver under the same conditions.

System	Watts
A-M	100
Unemphasized *F-M*	8
Pre-emphasized *F-M*	2

This indicates the possibility of greater transmission ranges with medium power levels which may allow some communication problems to be solved without repeating stations.

Other Advantages

Noise reduction is not the only achievement of frequency modulation as far as communication for power-line carrier is concerned. There are other characteristics which can be utilized to advantage in the various types of communication. The presence of a limiter in the *F-M* receiver is analogous to a very fast and flat type of automatic volume control. The automatic volume control used in *A-M* receivers is of necessity reasonably slow and usually not very flat. One type of communication wherein this characteristic is advantageous is the two-frequency duplex where one frequency is used to transmit in one direction and the other frequency is used to transmit in the opposite direction. The transmitter and receiver audio circuits must then connect to a hybrid circuit and can be set closer to the critical point if the audio output of the receiver is quite constant. Since the limiter in an *F-M* receiver can hold the output extremely constant, a two-frequency voice channel can be operated with higher audio gains, from terminal to terminal.

The other type of communication commonly used is the single frequency duplex or automatic simplex where the voice starts the transmitter and blocks the receiver on outgoing speech. To reduce the amount of clipping of words, it is desirable to accomplish the switching of the transmitter and receiver in as short a time as possible. One inherent limitation in an *A-M* system for fast switching of a channel is the surge of rectified carrier in the detector of a receiver when the transmitter starts. For smooth operation it is necessary to hold the receiver in an inoperative condition until this surge dies down. This difficulty cannot be completely overcome with an *A-M* system because turning the transmitter on and off is fundamentally amplitude modulation, and the detector is designed to detect amplitude modulation. When *F-M* is used, the detector in the receiver is insensitive to amplitude variations and is only sensitive to any phase variations that may come about in starting and stopping the transmitter. Since any phase shifts are small compared to the phase shift caused by modulation by the desired signal, this surge is greatly minimized in the receiver when *F-M* is used.

The transients in an automatic-volume-control circuit of an *A-M* receiver at the moment carrier is received prevents the possibility of opening the receiver quickly and getting an undistorted signal in the output. These transients in automatic-volume-control circuits change the gain of the receiver and hence the output of the receiver is modulated by these transients which causes distortion. On the other hand, a limiter in an *F-M* receiver is practically instantaneous in action, and the receiver can be opened very rapidly without the possibility of the receiver output becoming distorted by transients.

It has been shown[12,13] that two broadcast *F-M* stations operating on the same frequency have considerably more interference-free operating area than two *A-M* broadcast stations on the same frequency. This would still be true of two *F-M* power-line carrier communicaton channels, except to a lesser degree, since the deviation ratio is one to one instead of five to one. With the rapid installation of carrier-current apparatus throughout the country, there are many places where frequency congestion is becoming a problem. One partial solution to this problem would be by means of *F-M*, since a certain frequency could be repeated throughout a system more often than with amplitude modulation.

This paper has largely dealt with aspects of frequency modulation as applied to voice communication. Obviously, there are certain other services where *F-M* is much better than *A-M*. It has been demonstrated that a frequency-shift-type signaling channel[10] is superior in most all respects to a keyed-carrier type of signal channel. It is much easier to transmit frequency or phase accurately through nonlinear tube circuits than it is to transmit an amplitude faithfully through these same type circuits. Therefore, frequency modulation seems basically advantageous when tube circuits are involved. Also, all radio-frequency circuits associated with an amplitude-modulated signal must be linear whereas they need not be linear with a frequency-modulated signal.

Conclusion

It seems certain that the characteristics of *F-M* make it desirable for many applications in the carrier-current field. The outstanding characteristic of *F-M* is the rejection of the interference resulting from undesired amplitude modulation of the carrier.

The chief advantages for *F-M* when applied to power-lines may be summarized as follows:

1. Capability of noise reduction.
2. Possibility of longer channels or less power in transmitters.
3. Less interference between channels on the same frequency.
4. Flat automatic volume control in receiver.
5. Fast switching of channel possible in single frequency voice communication.
6. Same auxiliary apparatus as used for *A-M* channels because of the same band-width requirements.

These advantages have been discussed to a considerable extent in the body of the paper.

It should be pointed out that *F-M* equipment cannot be applied to operate with existing *A-M* equipment. A signal from an *F-M* transmitter can be reproduced by an *A-M* receiver by tuning the receiver to one side of the carrier[8] so that the selectivity characteristic performs similar to a slope filter. However, this is not acceptable for general application because of the distortion resulting from the nonlinearity and narrowness of the sloping part of the characteristic. Also, any frequency drift which may occur in the *F-M* carrier results in excessive distortion in the *A-M* receiver because the slope filter which is obtained by the one-

The Calculation of Unbalanced Magnetic Pull in Synchronous and Induction Motors

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Synopsis: Unbalanced magnetic pull may be defined as the net sideways force between the stator and rotor of an electric machine resulting from a difference in the air-gap flux densities on opposite sides of the machine. This difference in flux density is, in general, caused by a difference in the air gaps on the two sides.

There is outlined herein a method of calculation of unbalanced pull which takes into account the combined effects of saturation, parallels, and primary reactance. The increased accuracy which this method affords should make possible more accurate predictions of mechanical deflections and critical speeds.

I. Induction Motors

INDUCTION motors may operate at any speed from zero to synchronous speed and at any applied voltage from zero to 110 per cent of normal. Operation of the machine under these conditions may be illustrated on the no-load saturation curve. The no-load saturation curve will be represented by a power equation of the form:

$$i_m = eI_g + e^m I_g$$

Assume that the flux density over a certain section of the air gap of a machine is uniform and that a uniform change is made in the length of the air gap over this section while the magnetizing current is maintained at a fixed value. It is shown in Appendix I that the resulting change in gap density is given by the equation:

$$b = \frac{\left(1 - \frac{K_c'}{K_c}\frac{g-\Delta}{g}\right)eB_g}{\frac{K_c'}{K_c}\frac{g-\Delta}{g} + me^{m-1}\frac{I_z}{I_g}}$$

This equation may be used to give the rise in gap density caused by a given change in the air gap for an induction motor with a series or two-parallel primary winding operating at any speed and voltage. However, it should be noted that the no-load saturation curve does not accurately represent the flux conditions in the motor under load. Use of this curve is justified, however, by the fact that the total saturation will normally be divided fairly evenly between the stator and the rotor, and the density rise as calculated by the foregoing equation will be nearly correct.

If a very small deflection is considered, this equation has the following form:

$$b = \frac{\frac{\Delta}{g}eB_g}{1 + me^{m-1}\frac{I_z}{I_g}}$$

This equation may be written in the form:

$$b = K_g \frac{\Delta}{g} eB_g$$

where

$$K_g = \frac{1}{1 + me^{m-1}\frac{I_z}{I_g}}$$

and this represents the effect of saturation on the flux density rise.

A. Unbalanced Pull for a Series or Two-Parallel Primary Winding

Consider now a machine having constant flux density around the periphery in which the rotor is displaced to one side a small amount.

The deflection will then be approximately sinusoidal around the periphery, and the flux density change will also be approximately sinusoidal, since b = constant $\times \Delta$.

The fundamental formula for magnetic pull is:

$$\text{Magnetic pull} = 0.01386 B^2 A$$

Using this formula together with the equation for density rise, it is easily proved that:

$$\text{Unbalanced magnetic pull} = 0.01386 K_g \frac{\Delta}{g} e^2 B_g^2 A$$

In another form, this may be written:

$$\text{Unbalanced magnetic pull} = \text{constant} \times \frac{e^2}{1 + me^{m-1}\frac{I_z}{I_g}}$$

Solving for a maximum:

$$E^{m-1} = \frac{2}{(m^2 - 3m)\frac{I_z}{I_g}}$$

where E is the per unit voltage at which maximum pull occurs.

This formula gives the voltage at which maximum pull would occur if the gap density were uniform around the periphery of the machine. However, with a sinusoidal wave form and with part of the saturation in the teeth it is apparent that maximum pull for the entire wave will not occur when the peak density reaches the aforementioned value for maximum pull but will occur at some higher density. For an unsaturated machine, when the peak density reaches the aforementioned value, the average pull

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sided tuning of an *A-M* receiver is very narrow.

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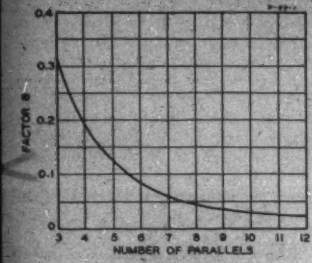


Figure 1. Factor *a* plotted against the number of parallels

will be one half the pull that would be obtained if the density were uniform at this value. However, with saturation, it is a close approximation to take this value as two thirds of the pull calculated with a uniform density. There is an important exception, however; that is, that, when the maximum pull comes at higher than 110 per cent voltage, the unsaturated value of one half should be used.

This gives two cases as follows:

1. For E less than 1.1

Maximum unbalanced pull =

$$2.88K_s E^2 \frac{B_g^2 A}{g} \times 10^{-6}$$

2. For E greater than 1.1

Maximum unbalanced pull =

$$2.62K_s \frac{B_g^2 A}{g} \times 10^{-6}$$

Both formulas apply to a deflection of $^1/_{32}$ inch.

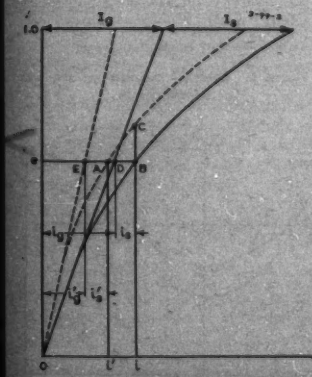


Figure 2. Air-gap flux-density change from the no-load saturation curve

B. Unbalanced Pull for Three or More Parallels in the Primary Winding

Assume a constant gap density under one parallel of the winding, and assume that the gap is changed a constant amount over this section. It is shown in Appendix II that the flux density rise is given by the formula:

$$b = \frac{\frac{\Delta}{g} e B_g}{1 + me^{m-1}\frac{I_s}{I_g} + \frac{1}{I_g X_1}}$$

This may also be written in the form:

$$b = K_R \frac{\Delta}{g} e B_g$$

where

$$K_R = \frac{1}{1 + me^{m-1}\frac{I_s}{I_g} + \frac{1}{I_g X_1}}$$

and represents the reduction in density rise because of saturation and primary reactance.

It is shown in Appendix III that if there are n parallels and r be any one of these parallels, the total pull of the rth parallel along a given line is given by the formula:

Total pull of rth parallel =

$$1.84\times10^{-6} e^2 \frac{B_g^2 A}{g}\left[\frac{\sin r\frac{4\pi}{n} - \sin(r-1)\frac{4\pi}{n}}{4}\times K_s + (K_R - K_S)\frac{n}{2\pi}\left\{\sin r\frac{2\pi}{n} - \sin(r-1)\frac{2\pi}{n}\right\} + \frac{\pi}{n}K_s\right]$$

For various numbers of parallels, this formula has the following forms:

3 parallels: unbalanced pull =

$$2.88\times10^{-6} e^2 \frac{B_g^2 A}{g}\,[0.315K_s + 0.685K_R]$$

4 parallels: unbalanced pull =

$$2.88\times10^{-6} e^2 \frac{B_g^2 A}{g}\,[0.188K_s + 0.812K_R]$$

6 parallels: unbalanced pull =

$$2.88\times10^{-6} e^2 \frac{B_g^2 A}{g}\,[0.087K_s + 0.913K_R]$$

8 parallels: unbalanced pull =

$$2.88\times10^{-6} e^2 \frac{B_g^2 A}{g}\,[0.045K_s + 0.955K_R]$$

12 parallels: unbalanced pull =

$$2.88\times10^{-6} e^2 \frac{B_g^2 A}{g}\,[0.022K_s + 0.978K_R]$$

Infinite parallels: unbalanced pull =

$$2.88\times10^{-6} e^2 \frac{B_g^2 A}{g}\,[0K_s + 1.0K_R]$$

Generally, the unbalanced pull may be expressed in the following form:

Unbalanced pull =

$$2.88e^2 \frac{B_g^2 A}{g}\,[aK_s + (1-a)K_R]\times10^{-6}$$

where a is determined from the curve of Figure 1.

From this equation, it is practically impossible to solve analytically for the voltage at which maximum pull will occur. However, a close approximation will be obtained, if we use in this formula the voltage at which the pull is a maximum, considering saturation alone.

With the constants that are used in most induction motors, the factor $[aK_s + (1-a)K_R]$ is approximately equal to K_s divided by the number of parallels. Therefore, the important fact is established that the unbalanced pull for an induction motor having three or more parallels in the primary winding may be obtained approximately by calculating the pull for a series winding and then dividing by the number of parallels.

II. Synchronous Motors

Synchronous motors have three distinct modes of operation as follows:

1. On open circuit with any speed from zero to synchronous and any field current from zero to full load field current.
2. Starting as an induction motor with any speed from zero to synchronous and any applied voltage from zero to 110 per cent of normal.
3. Normal synchronous operation with any applied voltage from zero to 110 per cent of normal, any field current from zero to full-load field current and any load.

A. Unbalanced Pull for a Series or Two-Parallel Stator Winding

A synchronous motor with a series winding on open circuit follows the same type of analysis as the induction motor

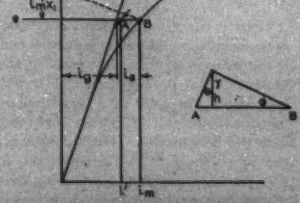


Figure 3. Flux-density change in one parallel of an induction motor

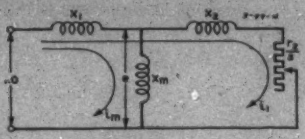


Figure 4. Equivalent circuit of the induction motor

with a series winding. Figure 2 and the equations derived from it apply except that they must be modified to take into account the field form of the synchronous motor. It has been found that this may be done quite accurately by multiplying the formulas for unbalanced pull previously given by C_1, the form factor of the wave.

Under conditions of starting or normal running, the relation between the air-gap flux density and the density in the iron parts of the machine may be different than the relation shown on the no-load saturation curve of Figure 2. However, as with induction motors, part of the iron carries higher flux than the air gap, while part carries lower. This tends to cancel out, and the magnetic pull calculated from the no-load saturation curve will be nearly correct for most machines.

Synchronous motors will normally be limited to about 120 per cent of normal air-gap flux density.

The following formulas, therefore, apply to a synchronous motor with a series or two-parallel stator winding:

1. For E less than 1.2

Maximum unbalanced pull =

$$2.88K_s E^3 \frac{B_g{}^3 A}{g} C_1 \times 10^{-4}$$

2. For E greater than 1.2

Maximum unbalanced pull =

$$3.11K_s \frac{B_g{}^3 A}{g} C_1 \times 10^{-4}$$

B. Unbalanced Pull for Three or More Parallels in the Stator Winding

There is one very important difference between unbalanced pull in induction and in synchronous motors when parallels are present. That is that the parallels will not reduce the pull in a synchronous motor at standstill on open circuit and with the field excited. For a consideration of pulling-over of the rotor, this is then the worst condition of operation, and the machine must be calculated as though it had only a series winding in the stator.

However, for a consideration of critical speed of the shaft the running condition must be analyzed, and it is with this problem that the remainder of this section will deal.

A synchronous motor during the starting period will have an unbalanced magnetic pull which can be calculated in the same way as an induction motor. The following formulas will apply:

1. For E less than 1.1

Maximum unbalanced pull =

$$2.88E^3 \frac{B_g{}^3 A}{g} [aK_s + (1-a)K_R] \times 10^{-4}$$

2. For E greater than 1.1

Maximum unbalanced pull =

$$2.62 \frac{B_g{}^3 A}{g} [aK_s + (1-a)K_R] \times 10^{-4}$$

In the case of a synchronous motor it will be necessary to use these two formulas rather than merely dividing the unbalanced pull for a series winding by the number of parallels. This is due to the fact that the magnetizing current is normally much larger in synchronous than in induction motors.

Consider now the case of a synchronous motor running on open circuit with any field current and with theoretically an infinite number of parallels. It is apparent that with a change in air gap, the flux density rise will be $X_1/(X_1+X_m)$ times the density rise that would have occurred if no parallels had been present. The quantity $X_1 K_s/(X_1+X_m)$ therefore becomes the factor K_R for this condition of operation. The resistance of the stator winding has been neglected, but it should be noted that as zero speed is approached, the resistance limits the circulating current and brings the pull up to the full locked rotor value.

Suppose that the motor is now operated synchronously with a fixed voltage, field current, and load, and a small change is made in the air gap by displacing the rotor to one side. The reduction in air gap on one side releases a certain number of field ampere turns and a certain number of armature reaction ampere turns to force more flux through the machine. This tends to raise the flux in the air gap, but this increase in gap flux produces a current component in the stator parallel (not necessarily in phase with the main current) which produces a leakage reactance plus armature reaction voltage drop exactly equivalent to the original density rise. The phase angle of the current increment is such as to produce an armature reaction exactly in opposition to the original density rise. The net density rise will then be $X_1/(X_1+X_m)$ times the original density rise which gives the same K_R as for the open-circuit condition. As before, use of the no-load saturation curve for the determination of K_s is not exact but is a justifiable approximation.

Since the gap density will be limited to about 120 per cent of normal, we have two cases as follows:

1. For E less than 1.2

Maximum unbalanced pull =

$$2.88E^3 \frac{B_g{}^3 A}{g} [aK_s + (1-a)K_R] C_1 \times 10^{-4}$$

2. For E greater than 1.2

Maximum unbalanced pull =

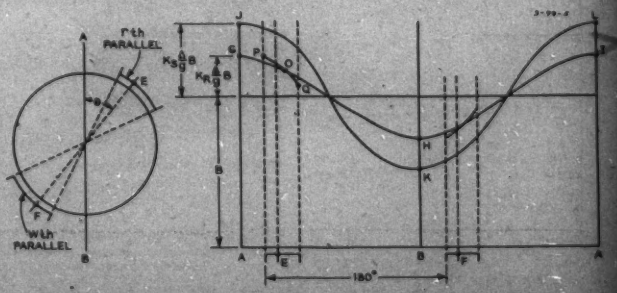
$$3.11 \frac{B_g{}^3 A}{g} [aK_s + (1-a)K_R] C_1 \times 10^{-4}$$

where

$$K_R = \frac{X_1}{X_1 + X_m} K_s$$

For most machines, it is found that there is a larger magnetic pull during synchronous operation than during the starting period. Consequently, only this condition need be calculated in order to obtain the worst possible unbalanced pull.

Figure 5. Effect of parallels on the flux density change



Summary

Formulas have been given for calculating first, the per unit voltage at which maximum pull occurs, and then the maximum unbalanced magnetic pull for a synchronous or induction motor with any number of parallels in the stator winding. All quantities used in the formulas may be taken directly from the design sheet with the exception of the exponent m which may be calculated from any two known points on the no-load saturation curve.

In deriving the equations, it was assumed that the air-gap deflection was a static deflection resulting from such causes as misalignment of the rotor in the stator, or the stator being out of round. The same type of analysis may be applied to a deflection that rotates with the rotor, and the same equations for unbalanced pull will apply.

The effect of parallel circuits in the rotor has been neglected, but it should be noted generally that with either a static deflection or a rotating deflection at a speed less than synchronous, the pull will be further reduced below the calculated values.

A two-pole machine will have less unbalanced pull than calculated for certain conditions of operation, but the formulas given should still be used to calculate the worst possible condition.

A two-parallel stator winding has been taken as the same as a series winding because a deflection along the line between the parallels will produce no compensating currents, and the pull will not be reduced. However, it should be noted that the pull will be reduced below the calculated value if the parallels of the different phases are spaced symmetrically around the machine or if the deflection is at right angles to the line between the parallels.

It is apparent then that the formulas given are either correct or somewhat pessimistic for all conditions of operation that could be considered as normal. Special cases of unbalance from such causes as short-circuited coils cannot be treated in a general method and should be solved individually as they arise.

Appendix I

Referring to Figure 2, assume a constant gap density over a section of the machine, and consider that a constant change is made in the air gap while the magnetizing current is kept constant.

$i_g = CK_c g$ and $i_g' = CK_c'(g-\Delta)$

$$i_g' = \frac{K_c'}{K_c}\frac{g-\Delta}{g} i_g$$

$$AB = ED = i_g - i_g' = \left(1-\frac{K_c'}{K_c}\frac{g-\Delta}{g}\right) i_g$$

But $i_g = eI_g$ and $i_s = e^m I_s$

$$i' = i_g' + i_s' = \frac{K_c'}{K_c}\frac{g-\Delta}{g} eI_g + e^m I_s$$

$$\frac{di'}{de} = \cot\theta = \frac{K_c'}{K_c}\frac{g-\Delta}{g} I_g + me^{m-1} I_s$$

$$\frac{BC}{AB} = \tan\theta = \frac{1}{\frac{K_c'}{K_c}\frac{g-\Delta}{g} I_g + me^{m-1} I_s}$$

$$BC = \frac{\left(1-\frac{K_c'}{K_c}\frac{g-\Delta}{g}\right) eI_g}{\frac{K_c'}{K_c}\frac{g-\Delta}{g} I_g + me^{m-1} I_s}$$

$$\frac{BC}{e} = \frac{b}{B} = \frac{\left(1-\frac{K_c'}{K_c}\frac{g-\Delta}{g}\right) I_g}{\frac{K_c'}{K_c}\frac{g-\Delta}{g} I_g + me^{m-1} I_s}$$

$$b = \frac{\left(1-\frac{K_c'}{K_c}\frac{g-\Delta}{g}\right) eB_g}{\frac{K_c'}{K_c}\frac{g-\Delta}{g} + me^{m-1}\frac{I_s}{I_g}}$$

Appendix II

Referring to Figure 3, assume a constant gap density under an independent section of the winding (a parallel), and assume that the gap is changed a constant amount over this section. The most pessimistic condition is obtained if in Figure 4 we assume that the secondary winding is open-circuited.

As proved previously:

$$i' = \frac{K_c'}{K_c}\frac{g-\Delta}{g} eI_g + e^m I_s$$

$$\frac{di'}{de} = \tan\theta = \frac{K_c'}{K_c}\frac{g-\Delta}{g} I_g + me^{m-1} I_s$$

$$\tan\phi = \frac{i_m X_1}{i_m} = X_1 \tan\gamma = \frac{1}{X_1}$$

$$AB = \left(1-\frac{K_c'}{K_c}\frac{g-\Delta}{g}\right) i_g = h\tan\theta + h\tan\gamma$$

$$h = \frac{AB}{\tan\theta + \tan\gamma} = \frac{\left(1-\frac{K_c'}{K_c}\frac{g-\Delta}{g}\right) eI_g}{\frac{K_c'}{K_c}\frac{g-\Delta}{g} I_g + me^{m-1} I_s + \frac{1}{X_1}}$$

$$\frac{h}{e} = \frac{b}{B} = \frac{1-\frac{K_c'}{K_c}\frac{g-\Delta}{g}}{\frac{K_c'}{K_c}\frac{g-\Delta}{g} + me^{m-1}\frac{I_s}{I_g} + \frac{1}{I_g X_1}}$$

If a small deflection is considered

$$b = \frac{\frac{\Delta}{g} eB_g}{1 + me^{m-1}\frac{I_s}{I_g} + \frac{1}{I_g X_1}}$$

Appendix III

Let there be n parallels total in each phase

Angular spread of each parallel $= 2\pi/n$ radians.

In Figure 5 the equation of curve JKL is $K_s(\Delta/g)B\cos\theta$. The limits on θ for the rth parallel are $(r-1)2\pi/n$ and $r2\pi/n$. The average value of JKL over the rth parallel $=$

$$\frac{1}{\frac{2\pi}{n}} \int_{(r-1)\frac{2\pi}{n}}^{r\frac{2\pi}{n}} K_s \frac{\Delta}{g} B\cos\theta\, d\theta$$

$$= \frac{n}{2\pi} K_s \frac{\Delta}{g} B\left[\sin r\frac{2\pi}{n} - \sin(r-1)\frac{2\pi}{n}\right]$$

Similarly, the average value of GHI over the rth parallel

$$= \frac{n}{2\pi} K_R \frac{\Delta}{g} B\left[\sin r\frac{2\pi}{n} - \sin(r-1)\frac{2\pi}{n}\right]$$

The drop in density under the rth parallel from the curve JKL to the final position at POQ

$$= (K_s - K_R)\frac{n}{2\pi}\frac{\Delta}{g} B\left[\sin r\frac{2\pi}{n} - \sin(r-1)\frac{2\pi}{n}\right]$$

Equation of $POQ =$

$$K_s \frac{\Delta}{g} B\cos\theta - (K_s - K_R)\frac{n}{2\pi}\frac{\Delta}{g} \times B\left[\sin r\frac{2\pi}{n} - \sin(r-1)\frac{2\pi}{n}\right]$$

Assuming a large number of poles compared to the number of parallels and that part of the saturation is in the teeth of the machine, it may be readily proved that the pull along the line AB

$$= \frac{0.01386}{\pi}\left(\frac{4}{3}\right) B b A \cos\alpha\, d\theta$$

For the rth parallel:

$$b = \frac{\Delta}{g} B\,[K_s\cos\theta - (K_s - K_R)B]$$

where

$$B = \frac{n}{2\pi}\left\{\sin r\frac{2\pi}{n} - \sin(r-1)\frac{2\pi}{n}\right\}$$

Total pull of the rth parallel along the line AB

$$= \frac{0.01386}{\pi}\left(\frac{4}{3}\right) B^2\frac{\Delta}{g} A \int_{(r-1)\frac{2\pi}{n}}^{r\frac{2\pi}{n}} \{K_s\cos^2\theta - (K_s - K_R)\beta\cos\theta\}\, d\theta = 1.84\times10^{-6} B_g^2 A \frac{\Delta}{g} \times \left[\frac{\sin r\frac{4\pi}{n} - \sin(r-1)\frac{4\pi}{n}}{4} K_s + (K_R - K_s)\frac{n}{2\pi} \times \left\{\sin r\frac{2\pi}{n} - \sin(r-1)\frac{2\pi}{n}\right\}^2 + \frac{\pi}{n} K_s\right]$$

Characteristics and Applications of Selenium-Rectifier Cells

E. A. HARTY
MEMBER AIEE

Synopsis: The rectification properties of selenium cells were first discovered in the year 1883. C. T. Fritts described them in the *American Journal of Science*.[11,12] However, they were never used to any extent, except possibly as photocells.

After the introduction of the copper-oxide rectifier, research activities were stimulated, and selenium cells were again rediscovered. The first commercial cells were made in Germany in the early '30's, and, as the technique of manufacture improved, better cells were made with better life expectancy.

The General Electric Company, after a period of developmental activity, started to make cells in 1938, first in its research laboratories, and subsequently a manufacturing plant was set up which permits producing cells in large quantities within relatively close electrical tolerances.

This paper contains data pertaining to these cells particularly, and the information may not apply in detail to cells manufactured by other methods without some correction factors.

Construction

THE selenium rectifier cell consists essentially of a carrier plate made of either aluminum or iron, supporting on one side a very thin film of specially treated selenium. The adhesion is quite intimate to prevent contact losses. This selenium film is given a series of controlled heat treatments to obtain a suitable crystalline structure.

Finally, a low melting point alloy is metal-sprayed onto the selenium surface. This layer is known as the "counter-electrode."

By means of subsequent electrochemical processes a film or blocking layer is formed between the counterelectrode and the selenium surface. Current flows freely between the selenium and the counterelectrode and is practically blocked in the other direction. Figure 1 shows a typical cross section of a cell.

Theory

Several theories have been suggested to explain the action of rectifiers of the type under discussion. The physicists do not all agree, and, therefore, no attempt will be made to discuss all these theories in detail.

One of the theories that appears the most logical to understand and that applies to all types of metal rectifiers is the following:

Metal rectifiers consist essentially of a semiconductor and a good conductor separated by a barrier or blocking layer which is, in itself, an insulator but through which electrons can pass in either direction. In the selenium rectifier the selenium layer is the semiconductor and the sprayed-metal counterelectrode the good conductor, the barrier or blocking layer being formed between these two substances. The sprayed-metal layer has an abundance of free electrons, while in the selenium layer, which is a relatively poor conductor, the free electrons are quite small.

When the two electrodes are connected to a source of supply, the opposite-polarities set up an electric field across the barrier or blocking layer. Since this layer is very thin, a comparatively small electromotive force will produce a steep potential gradient. If the sprayed metal

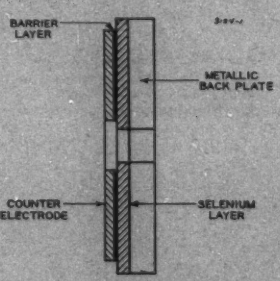


Figure 1. Cross section of a selenium cell

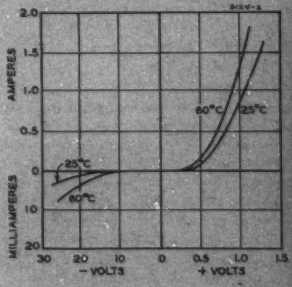


Figure 2. D-c characteristics

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Appendix IV. Nomenclature

A—Area of the stator bore in square inches.
g—Single air gap in inches.
g'—Single air gap with the rotor displaced ($g - \Delta$) in inches.
Δ—Amount the rotor is displaced from the center of the stator in inches.
K_c—Carter's coefficient for an air gap g.
K_c'—Carter's coefficient for an air gap g'.
B_g—Air-gap flux density at normal voltage in kilolines per square inch.
B—Air-gap flux density at any voltage.
b—Rise in the gap flux density.
e—Voltage in per unit corresponding to air-gap flux.
E—Per unit voltage at which maximum pull occurs.
I_g—Magnetizing current for the air gap at normal voltage.
I_s—Magnetizing current for saturation at normal voltage.
i_m—Magnetizing current at any voltage.
X_1—Stator leakage reactance in per unit.
X_m—Magnetizing reactance in per unit.
C_1—Form factor of the no-load field form of a synchronous motor.
m—Saturation curve exponent defined by $i_s = e^m I_s$.
K_s—Factor allowing for the effect of saturation on density rise.
K_R—Factor allowing for the effect of saturation and primary reactance on density rise.
σ—Factor depending on the number of parallels.

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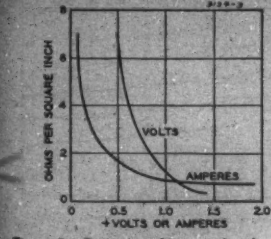

Figure 3. Resistance change with voltage or current

is connected to the negative pole of the source, the free negative electrons are accelerated to a sufficient velocity to enable them to pass through the barrier layer and the intercrystalline spaces of the selenium and reach the metal supporting disk, with the result that a flow of electrons is established which constitutes a current of electricity in the forward direction. When the polarity is reversed, the same action takes place in the opposite direction, but, since the number of free electrons in the semiconducting selenium is less than in the metal disk, the resulting current is much smaller. Because of this asymmetrical property, it is possible to rectify alternating current.

Electrical Characteristics of the Elements

Because it is almost impossible to make all cells exactly alike as to characteristics, even though materials and manufacturing methods are held within very close limits, the data that follow and also all published curves should be considered as representing average conditions. A slight deviation should be expected between individual cells.

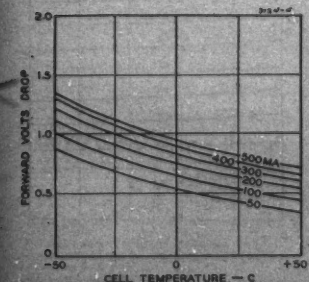

Figure 4. Temperature–forward voltage characteristics

One square inch area

D-C Characteristics

If a d-c voltage of varying potential is impressed first in the blocking direction and then in the flow direction and readings taken of the current that flows, a curve as shown in Figure 2 is obtained. This curve is based on selenium cells having one square inch of effective rectifying area.

In a similar way Figure 3 shows resistance versus voltage and resistance versus current. It should be noted and remembered that these curves are nonlinear and that they do not obey Ohm's law.

Effect of Temperature

The selenium rectifier cells have negative temperature coefficient which results

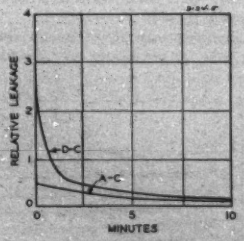

Figure 5. Leakage–time characteristics

in current increasing for a given voltage as the temperature goes up and decreasing as the temperature goes down.

Figure 4 shows this relation.

It should be noted that temperature also affects the leakage current in the blocking direction as shown on Figure 2.

Because of this characteristic, ratings should be such that the losses caused by heating should be kept under control; otherwise they may keep on adding, resulting in overheating and the eventual destruction of the rectifying film. In general, it may be stated that the rectifier will operate satisfactorily in a range of ambient temperature from −50 to +50 degrees centigrade.

Forward Characteristics and Stability

The forward characteristic is very stable when a-c or d-c voltage is applied in this direction. However, as the cell heats up, changes occur. Over a period of time, the resistance of the cell appears to change and take a set. The rate of change increases with cell temperature, and at 100 degrees centigrade the cell is damaged.

An increase in forward resistance with time means that the difference between the input voltage and the output voltage will become greater. Therefore, to maintain a given output voltage constant, it is necessary to increase the input voltage. Great care must be taken to rate correctly these rectifier cells when new to prevent overloading in voltage after aging takes place.

Reverse Characteristics and Stability

The reverse or leakage characteristic on alternating current is quite good; it is, in general, higher initially but creeps to a minimum value in about two to three minutes. However, when a selenium rectifier cell is subjected to a d-c voltage in the inverse direction, the leakage current is very high initially. A polarizing action similar to that observed with electrolytic capacitors takes place, resulting in a steady decrease in current with time. Typical leakage voltage–time character-

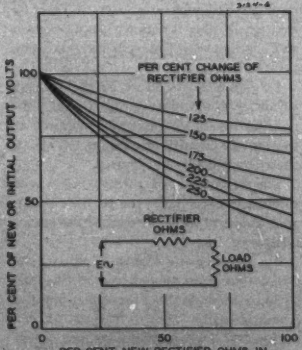

Figure 6. Effect of changing rectifier resistance on output

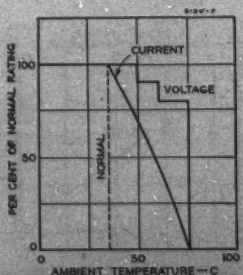

Figure 7. Rating of cells at high ambients

istics are shown on Figure 5. When the cells are continuously de-energized over a period of time, the reverse leakage resistance tends to decrease but will rapidly increase after the cells are again energized. It should again be noted that this same type of characteristic is also present in electrolytic capacitors. This characteristic should be borne in mind when applying these cells in blocking circuits, especially if instantaneous operation is required such as in certain types of high-speed relaying circuits.

Capacitance

A certain capacitance exists because of the presence of the barrier or blocking layer between the two electrodes of the rectifier cell. Measurements indicate this to be of the order of 0.02 microfarad per square centimeter. This may vary somewhat, depending on the past history of the cell.

In high-frequency applications, the capacitance acts like a shunt acrosss each cell, resulting in lowering the leakage resistance and changing the ratio of the forward to the reverse resistance. At normal a-c frequencies up to 2,000 cycles, the capacity effect usually can be disregarded.

Rectifier Circuits

Selenium rectifier cells are readily combined into series and parallel groups, depending on the voltage and current output required. These are used in rectifier circuits to change alternating currents to direct currents. The choice of the particular rectifier circuit rests with the designer. In view of the fact that rectifiers are used by many engineers who are not familiar with these circuits, a tabulation of the more popular circuits is included with this paper. (See Figure 19.)

It should be noted that these data apply to perfect sine waves, perfect rectifiers having no internal resistance and also no leakage whatsoever in the blocking direction. The load is based on a non-inductive resistance.

Calculations made with the aforementioned data are only of theoretical use and cannot be applied to actual design work without using correction factors.

Selenium rectifier cells have a fundamental resistance characteristic; this resistance is not constant and varies with current, temperature, and also time. Therefore, computations arrived at from formulas are not absolute, unless all these variables are considered. Design work should be based on empirical data based on years of experience to avoid trouble. Any correction factors must also have their own correction factors, since these will vary with time, temperature, and current.

In designing a practical selenium rectifier circuit, it is evidently very essential to pay particular attention to the fact that the rectifier resistance is not constant and changes with time, current, and temperature.

To minimize its effect on the rectifier circuit, it is quite essential to make the rectifier resistance small as compared to the total circuit resistance.[4] This is shown graphically in Figure 6.

The recommended ratings have been so chosen as to make the rectifier resistance about 10 to 15 per cent of the circuit resistance.

By referring to Figure 6, it can be noted that even though the rectifier resistance may double, the effect on the circuit is small.

However, when rectifiers are overloaded, the rectifier resistance in effect becomes a larger percentage of the circuit resistance, and, therefore, more changes should be expected in the output as readily shown in Figure 6.

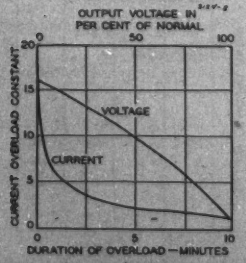

Figure 8. Overload rating of selenium cells

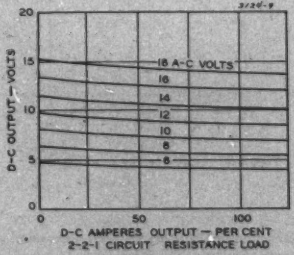

Figure 9. A-c to d-c characteristics of single-phase unit bridge rectifier with resistance load

One square inch area, 25 degrees centigrade

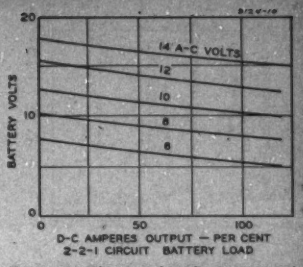

Figure 10. A-c to d-c characteristics of single-phase unit bridge rectifier with battery load

One square inch area, 25 degrees centigrade

Maximum Ratings

Table I and II show the voltage and current ratings for the various size cells which are available at the present time.

The circuit names as used by the metallic rectifier industry have been retained in Tables I and II.

The circuit symbolic notation is an attempt to overcome the objections raised to the circuit names by replacing them by a symbolic equation 3.

The first digit is the reciprocal of the fraction of time a cell carries current during the cycle. The second digit shows the cells in series and the third digit the cells in multiple carrying current instantaneously. This notation applies to unit rectifiers.

These ratings are based on the usual limiting factors of temperature rise, aging, and voltage breakdown. The in-

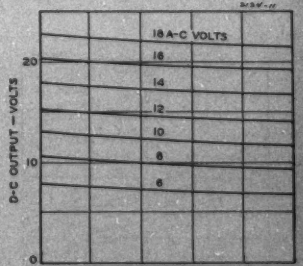

Figure 11. A-c to d-c characteristics of three-phase rectifier, bridge type, with resistance load

One square inch area, 25 degrees centigrade

Table I. Rating as Valves at 35 Degrees Centigrade

Code letter	F	A	C	H
Diameter of cells	1 Inch	1½	2⅝	4¾
Inverse rms volts	18	18	18	18
Blocking volts d-c	15	15	15	15

ternal losses heat the rectifier cell, and the final permissible total temperature limits the output rating. It should be borne in mind that aging increases the heating, and, therefore, it is very important to run the rectifier cells somewhat cooler when new. This factor has been taken into consideration in the published ratings. The relation of cell spacing to cell diameter in a rectifier-stack assembly has been chosen for optimum cooling.

Permissible Temperature Rise

Although selenium rectifier cells may be operated up to a total temperature of

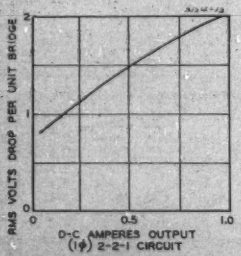

Figure 12. Rms volts drop in a unit bridge single-phase rectifier at different values of current

One square inch area, 25 degrees centigrade

75 degrees centigrade, the ratings given in the previous paragraph are based on an ambient temperature of 35 degrees centigrade allowing a maximum temperature rise of 40 degrees centigrade. However, if the normal temperature is liable to be exceeded, the full-load ratings must be changed and reduced to prevent the total temperature from exceeding 75 degrees centigrade.

Figure 7 shows the recommended practice.

Overload and Intermittent Rating

Selenium rectifier cells will withstand short-time current overloads beyond the normal current, provided the cell is not heated above 75 degrees centigrade. If the cell is allowed to cool back to normal between loading periods, higher current overloads can be applied than in the case of insufficient cooling periods.

Figure 8 shows permissible current overload data and also how the voltage drops as the current increases.

Voltage overloads are not permissible, even for short periods, because of the danger of breaking down the blocking layer.

If the breakdown current is limited, the punctured cells sometimes self-heal. However, every healed spot robs the rectifying surface of some cross section, resulting in increasing effective resistance of the cell.

Unit Rectifier

For convenience in designing rectifiers, data have been prepared on a unit rectifier. This can be defined as any rectifier circuit having one cell in each

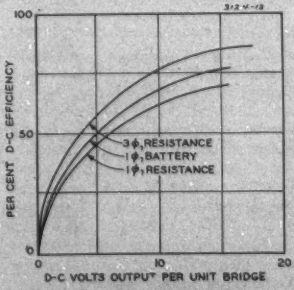

Figure 13. Efficiency of selenium cells at full-load current

Full-load amperes, 25 degrees centigrade

arm. By reducing all measurements to a unit rectifier, it is possible to obtain general data that will apply to any rectifier, providing the number of cells in series in each arm is known. These same data can also be applied where two or more unit rectifiers are operated in multiple.

A-C–D-C Characteristics of a Single-Phase Full-Wave Unit Bridge Rectifier With a Resistance Load

By impressing various voltages across a unit bridge rectifier, a group of curves may be obtained as in Figure 9, showing d-c voltages plotted against d-c amperes output for various impressed a-c voltages.

A-C–D-C Characteristics of a Single-Phase Full-Wave Unit Bridge Rectifier as a Battery Charger

If the resistance load is replaced by a battery load, and data as shown previously are again repeated, a family of curves as shown in Figure 10 is obtained.

A-C–D-C Characteristics of a Three-Phase Full-Wave Unit Bridge Rectifier

If a three-phase rectifier is operated at different a-c voltages and different loads, a family of curves as shown in Figure 11 is obtained.

A-C Volts Drop Within a Unit Bridge Rectifier

If a d-c ammeter is used as a load across a unit bridge rectifier and the a-c input is varied, a curve as shown in Figure 12 is obtained. This permits calculating the a-c input voltage provided correction factors are used, depending on the circuit and its form factor.

Efficiency

Because of the presence of an a-c component in the d-c output of all rectifiers, it is quite essential to use the correct type

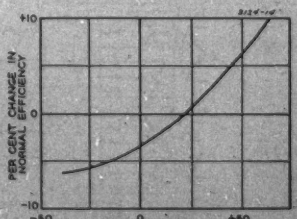

Figure 14. Correction curve to obtain efficiency at different temperatures

Table II. Current Ratings at 35 Degrees Centigrade for Resistance and Inductance Loads

Circuit	1 Inch	1½ Inches	2⅝ Inches	4¾ Inches	D-C Volts	Circuit Symbolic Notation
One-phase half-wave	0.075	0.2	0.500	2.15	6	1-1-1
One-phase bridge	0.150	0.4	1.00	4.3	12	2-2-1
One-phase center tap	0.150	0.4	1.00	4.3	6	2-1-1
Three-phase half-wave	0.200	0.5	1.25	5.3	8	3-1-1
Three-phase bridge	0.220	0.600	1.4	6.5	16	3-2-1
Three-phase center tap with no interphase coil	0.270	0.7	1.8	8.0	8	6-1-1
Three-phase center tap and interphase coil	0.400	1.0	2.5	11.0	8	3-1-2
D-c valves	0.120	0.320	0.80	3.0	15	1-1-1

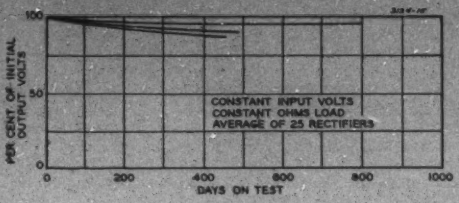

Figure 15. Aging of selenium rectifiers

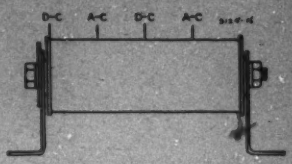

Figure 16 (right). Full-wave single-phase rectifier-stack assembly

of instruments to measure the power output.

The input is always measured with an a-c wattmeter and reads all of the power delivered to the rectifier.

If the nature of the load is such that both the a-c and d-c components of the rectifier output produce useful work, then an a-c wattmeter in the output measures the correct output. Examples of this type of load are resistances, lamps, radio-tube filaments, electromagnets, series motors, and so forth.

However, if the a-c component is not utilized, then the output should be measured with a d-c voltmeter and d-c ammeter of the D'Arsonval type. For example, battery charging, plating work,

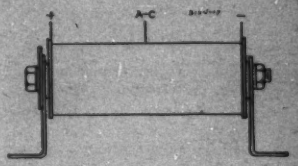

Figure 17 (right). Half-wave three-terminal-type rectifier-stack assembly

Figure 18 (right). Half-wave two-terminal-type rectifier-stack assembly

Figure 19 (below). Fundamental rectifier circuits

Symbolic Notation	Circuit	Output Wave Values: Wave Form	E_{avg}	E_{eff}	Form Fact.	D-C Ripple %	Rectifier Cell-Wave Values: Wave Form	I_{avg}	I_{eff}	Form Fact.	E Inverse	Trans. Capacity: Pri.	Sec.
1-1-1			0.45 E_{rms}	0.707 E_{rms}	1.57	121		1.00 I_{dc}	1.57 I_{dc}	1.57	1.414 E_{rms}	3.49 EI_{dc}	3.49 EI_{dc}
2-1-1			0.900 E_{rms}	1.0 E_{rms}	1.11	48		0.500 I_{dc}	0.786 I_{dc}	1.57	2.828 E_{rms}	1.235 EI_{dc}	1.75 EI_{dc}
2-2-1			0.900 E_{rms}	1.0 E_{rms}	1.11	48		0.500 I_{dc}	0.786 I_{dc}	1.57	1.414 E_{rms}	1.235 EI_{dc}	1.235 EI_{dc}
3-1-1			1.17 E_{rms}	1.19 E_{rms}	1.02	21		0.333 I_{dc}	0.587 I_{dc}	1.76	2.45 E_{rms}	1.508 EI_{dc}	1.506 EI_{dc}
4-1-1			1.27 E_{rms}	1.28 E_{rms}	1.005	11		0.250 I_{dc}	0.502 I_{dc}	2.01	2.828 E_{rms}	1.116 EI_{dc}	1.58 EI_{dc}
6-1-1			1.350 E_{rms}	1.351 E_{rms}	1.001	4		0.167 I_{dc}	0.408 I_{dc}	2.45	2.828 E_{rms}	1.28 EI_{dc}	1.81 EI_{dc}
3-1-3			1.170 E_{rms}	1.170 E_{rms}	1.001	4		0.167 I_{dc}	0.293 I_{dc}	1.76	2.45 E_{rms}	1.088 EI_{dc}	1.51 EI_{dc}
3-2-1			2.340 E_{rms}	2.341 E_{rms}	1.001	4		0.333 I_{dc}	0.579 I_{dc}	1.74	2.45 E_{rms}	1.047 EI_{dc}	1.047 EI_{dc}

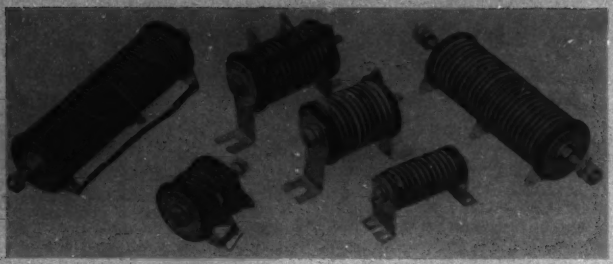

Figure 20. Typical selenium rectifiers for industrial applications

chemical work, electrolysis, shunt motors, and so forth. Therefore, the efficiency can be expressed as either

$$\text{RMS efficiency } \% = \frac{\text{a-c watts output}}{\text{a-c watts input}} \times 100$$

or

$$\text{D-c or average efficiency } \% = \frac{\text{d-c volts} \times \text{d-c amperes}}{\text{a-c watts input}} \times 100$$

In polyphase work, the rms efficiency approximately equals the average efficiency.

However, in single-phase work, there is a difference of approximately 15 points in efficiency between the average and rms values, the latter being the highest.

Typical efficiency curves are shown in Figure 13 at different voltages and at full-load current densities. Figure 14 shows correction factors at different temperatures.

Life Tests

General Electric selenium rectifiers have undergone extensive tests and show promise of better aging characteristics than some of the European elements previously tested.[4] Typical life tests are shown in Figure 15. It should be noted that these tests represent aging as seen from the user's viewpoint.

Practical Rectifier Design

It is believed that a worked-out example will show how to use the data contained in this paper.

For example, assume that we want a 30-volt rectifier at one ampere working on a resistance load from a single-phase circuit. By reference to the tabulation on ratings, we find that the most voltage we can obtain from a unit bridge rectifier at full current density for each type cell is 12 volts. Dividing 30/12 = 2.5, therefore, three is the minimum number of series cells to be selected.

The voltage to be supplied by each unit bridge rectifier will be 30/3 = 10. By reference to Figure 9, we find that, at full-load current and ten volts, we need 13.2 volts alternating current per bridge, or 3 × 13.2 = 39.6 for the rectifier under discussion.

The size of the cell can be determined by reference to the tabulation on ratings. To carry one ampere a type *C* cell having $2^{9}/_{16}$-inch diameter is required. If the current rating required does not match that of the four available sizes, then it will be necessary either to operate at slightly less than full rating or to use several smaller cells in multiple.

From the aforementioned calculations, to obtain 30 d-c volts at 1.0 ampere direct current, a bridge rectifier using three cells in series would be required. The a-c input is 39.6 volts, and the transformer should have sufficient taps to take care of line voltage variations. To take care of aging, it is advisable to tap the transformer up to 3×18 rms volts or 54 volts. The approximate efficiency is 63 per cent at 25 degrees centigrade as seen from Figure 13 and will be higher at the operating temperature as shown on Figure 14.

Construction of Selenium-Rectifier Stacks

Selenium rectifier cells are assembled into either full-wave or half-wave stacks, depending on their voltage and current rating. Low-voltage stack can generally be assembled into single stack, using a construction as shown in Figure 16.

For higher voltages, two stacks are sometimes used, embodying a construction as shown in Figure 17.

For still higher voltages four units are used as shown in Figure 18.

The cells are spaced to permit free ventilation on both sides, light spring washers being used to collect current.

The stacks are clamped under light pressure and come either with or without mounting brackets as shown in Figure 20.

Installation of Rectifier Stacks

Selenium rectifier stacks should be installed in well ventilated cabinets to permit free circulation of air.

They should be located preferably at the bottom of cabinets so that any heat from other heat dissipating apparatus does not have a cumulative effect.

If installed in closed cabinets, a certain amount of derating should be made to take care of the higher internal ambient temperatures as previously explained.

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A New High-Interrupting-Capacity Fuse for Voltages Through 138 Kv

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ASSOCIATE AIEE

Synopsis: The reliable performance of high-interrupting-capacity fuses in the intermediate voltage field has led to an increased interest in the application of such fuses for the higher voltages. Unfortunately, a fuse for the higher voltages cannot be made by simply enlarging or lenghthening the lower-voltage devices. To interrupt the higher currents in a reasonable structure, arc lengths must be kept short to reduce mechanical stresses. Interruption in these short distances creates high dielectric stresses external to the fuse that would endanger the operation of a device built along conventional lines. Adequate conductors for carrying the higher currents through the longer-length fuse must be moved quickly during interruption.

A new high-voltage fuse in which interruption of the higher currents is accomplished in a short length without undue voltage stresses adjacent to the fuse has been developed. This fuse has a new arrangement of conductors which permits rapid extension of the arc without expulsion of any conductor parts from the fuse. All this has been accomplished with a fuse of such light weight that it permits the use of a drop-out design which is a necessity at the higher voltages to prevent subsequent flashovers caused by leakage currents. The interrupting medium is compressed boric acid which has proved very effective and reliable at the lower voltages. Repeated interrupting and mechanical tests have demonstrated the suitability of the new fuse for service on important transmission circuits.

PRESENT day requirements relating to the transmission of large blocks of electrical energy to large industrial areas and new war industry plants remote from power generation plants demand short-circuit protective devices that will afford the maximum protection with a minimum outlay of critical materials. The excellent operating record established by modern high-interrupting-capacity power fuses in the intermediate voltage field has created an insistent demand for fuses suitable for application on transmission systems in the 44-kv to 132-kv class. Power fuses require less critical material than a conventional hook-stick-operated disconnect switch and can be mounted in the same space, thus effecting economies in substation space and structure. Certain operating characteristics of high-capacity power fuses provide for the maximum continuity of service so essential to modern production methods. Power fuses when applied for the short-circuit protection of transformers or circuits provide ultrahigh-speed clearing of faults. Faulted equipment is isolated from the system in a small fraction of the time required by conventional short-circuit protective devices, thus greatly reducing the damage to the equipment and enabling it to be repaired and returned to service at a much earlier date. Operating speeds equal to or less than the most modern ultra-high-speed circuit interrupters insure maximum system stability since the voltage dip associated with a fault persists for as short a period as one cycle. The short duration of voltage fluctuation insures that relays elsewhere on the system will not operate to stop important continuous process loads. The high-speed operation of power fuses reduces the requirements for elaborate relaying schemes on new transmission circuits and eliminates the need for extensive relay changes when new load centers are added to an existing transmission line.

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Requirements for Higher-Voltage Power Fuses

Since electrical power circuits operating at 44 to 132 kv are intended for the transmission of large blocks of energy, it follows that such systems are connected to a generating source of considerable capacity, capable of delivering a correspondingly high value of short-circuit energy to a fault. Unlike conventional circuit breakers which require as long as eight cycles to interrupt a fault and are so rated, power fuses frequently operate in the first half cycle of a fault; hence they may have to interrupt a fully displaced or asymmetrical current. For the systems under discussion the rms value of this current may be as much as 1.6 times the symmetrical short-circuit current. This ratio of currents is dependent on the characteristics of the transmission circuit. The closer the fault is to the generating source the greater ratio of reactance to resistance and the higher the ratio of asymmetrical to symmetrical current which approaches the theoretical limit of 1.73. From this it can be seen that power fuses for use on high-voltage circuits must have an interrupting capacity considerably in excess of the symmetrical short-circuit current. To handle the most severe case a fuse for 1,000,000-kva systems must be able to interrupt at least 1.6 times the current value corresponding to a 1,000,000-kva symmetrical fault. It is obvious therefore that a fuse for use at the higher voltages

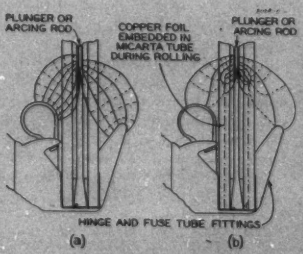

Figure 1. Approximate plot of dielectric field at lower end of fuse bit

Note how electrostatic shielding in diagram b reduces the lines of force or potential gradient at the lower fittings. The reduction of potential gradients at these points eliminates the possibility of external flashovers

(a). Without electrostatic shield

(b). With electrostatic shield

Figure 2. Single-pole unit, 92 kv, 200 amperes

must have a high interrupting capacity.

A second requirement is the ability to interrupt positively the entire range of fault currents from the minimum melting current of the fusible element up to its full interrupting rating. While such fuses are normally applied solely for short-circuit protection, it is recognized that certain types of high impedance faults may develop, transformer secondary protective devices may be inoperative, or that faults may develop in a period of light generating capacity, requiring interrupting at low values of fault current.

A further requirement, especially important at these higher circuit voltages, is that the restored voltage shall not overstress the insulating material, making up the fuse tube so that there are high leakage currents which may result in flashover or dielectric breakdown. Since circuits of this voltage are sometimes supplied from hydroelectric plants where the sudden dropping of a large load may cause "runaway" of the generators before protective relays operate, the restored voltage may rise to a value double the normal circuit voltage. These conditions make it imperative that the higher-voltage fuses be automatically removed from the circuit immediately after operating.

Additional requirements particularly important to enable operating personnel to locate blown fuses and replace these with new units are positive indication of blown fuses and a lightweight simple unit that can readily be removed and replaced in the fuse support.

Evolution of the New Fuse

An analysis of the characteristics of the dry-type high-interrupting-capacity fuses for operating voltages up to 34.5 kv reveals that there are four major design features which have been responsible for its exceptional performance record.

1. Boric acid in the dry molded form as the lining of the interrupting chamber will interrupt a much higher voltage per inch of length than horn fiber on other fuse-tube materials in an equivalent structure. Since this is

Figure 4. Fuse unit with disconnecting fittings

especially true in the lower range of currents, fuses utilizing boric acid can be made in a shorter length. At the higher currents this shorter-length boric-acid-lined fuse tube does not produce as vigorous a gas blast as the equivalent longer length of fiber; consequently, mechanical stresses in the tube structure are much less. In addition, the voltage gradient that can be interrupted increases with current much more rapidly. The gases evolved from boric acid are noncombustible and have a much higher dielectric strength than gases from organic materials and are much less liable to cause breakdown between adjacent line parts.

2. The very high interrupting capacity of this type of interrupter is largely due to the use of a very short fuse element in an enlarged opening of the fuse tube that is freely vented and the drawing of the arc into a more restricted section of the interrupting chamber. There is sufficient gas blast from the boric acid even in this enlarged opening to interrupt the higher currents at the end of the first half cycle of arcing without developing excessive pressures.

3. The use of a solid-rod-type conductor through the arcing chamber further increases reliability of high current interruptions, since there is no flexible conductor or cable to become jammed in the fuse tube by the gas pressure developed on very high fault currents.

4. Interruption of extremely high currents without excessive internal pressure and without severe voltage surges is further accomplished by the use of controlled mass and acceleration of the arcing terminal through the interrupting chamber. The mass of the arcing rod and of the operating spring and shunt assembly is so co-ordinated with the tension of the spring that the arcing rod is accelerated only a few inches or only a fraction of the length of the interrupter in the first half cycle. This short-length arc in the enlarged opening results in minimum mechanical stress in the fuse structure.

The first problem of the designer in converting low-voltage fuse structures to a design suitable for the higher voltage is to determine a suitable length of fuse. Since in the interests of simplicity of handling and replacement by operating personnel, it is desirable to have a disconnecting-type fuse, the minimum length of the fuse is automatically set by the standards for such types of equipment. The actual length of the fuse unit is then dependent upon the required length of interrupting chamber to secure efficient interruption throughout the entire current range. The voltage gradient that can be interrupted in a boric-acid interrupter varies with the diameter of the openings in the boric acid. Furthermore the voltage gradient is not constant for a given bore but varies with the length. For longer lengths, the voltage that can be interrupted corresponds to approximately the 1.7 power of the length. A large bore is required for in-

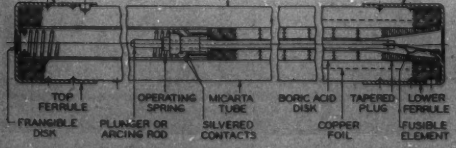

Figure 3. Cross section of new fuse unit

The unit for 138 kv is 72 inches long and 2 1/2 inches in diameter

Figure 5. Sleet hood with dropout mechanism

Note the trigger which is actuated by the moving plunger to initiate the dropout action

terruption of the higher fault currents to minimize mechanical stresses; however, it would be impractical to build such high-voltage fuses with a constant bore as the length required to interrupt currents in the lower range would be excessive. To make the fuse as short as possible, a stepped or tapered bore is used with the largest opening in the vented end so that gases are readily vented on high-current shots and the bore gradually decreasing to a diameter just larger than the size of the conductor rod. In this way, the fuse can be made just as short as the permissible open-gap spacing for a disconnecting-type unit, since the lower currents are readily interrupted when the arc is drawn into the more restricted bore. The use of the conventional spring and shunt assembly is not practical in the higher-voltage fuse as the collapsed length of such an assembly is approximately one third the length of the entire fuse unit. Therefore, to make the fuse unit as short as desired, a new method of conducting current from the top ferrule to the solid arcing rod has been developed which occupies a length equivalent to the length of the interrupting chamber.

After the minimum length has been established, the next step in the evolution of the higher-voltage fuses is to determine the form of the fuse unit. From a weight and handling standpoint, the use of insulating tube of organic material with a porcelain weatherproof casing is at once ruled out. Since it is recognized that organic insulation, such as a fuse tube, should not be subjected to high-voltage stress, such as restored voltage, after the fuse has blown, a drop-out-type fuse is indicated.

The decision to make a drop-out-type fuse entails further design problems, notably the necessity for a lightweight construction to eliminate any shock to the insulator column supporting the pivot end of the long fuse tube. The use of a permanent fuse holder with a renewable element or refill as has been used with such success in the lower-voltage fuses must be eliminated to avoid duplication of structure. In a design incorporating a renewable refill, the refill unit must be mechanically strong enough to withstand the entire pressure developed in the interupting chamber during interruption of the maximum fault current and as the pressures in the refill are communicable to the fuse holder, the holder must be of equally sturdy construction. The decision to make the higher-voltage fuses in a single nonrenewable unit was aided by early tests on a refill- and holder-type unit. With the lengths involved for the higher voltages it is virtually impossible to maintain the extremely close clearances between the outside of the refill tube and the inside of the holder tube required to prevent flashover in this space. The presence of ionized gases within the holder and the high-voltage gradients present in this space on high current interruption were very conducive to flashovers in this space. As the length of the interrupter increases, the voltage that can be interrupted increases faster than the dielectric strength of the adjacent air gap.

With lightweight construction a paramount requisite, it is imperative that the interrupter be very efficient so that the

Figure 6. Hinge with fuse unit

mechanical stresses resulting from gas pressures developed do not require an excessively strong and heavy structure. The efficiency of an interrupter is based on building up high dielectric strength in the arc path at current zero with low arc voltage and correspondingly low arc energy. An efficient fuse design is based on drawing an arc as short as possible in a structure offering a minimum of actual restriction to the arc core and develop sufficient un-ionized gases to effect interruption at first current zero. The interruption of high currents in such a short length imposes very severe dielectric stresses between the end of the arcing rod and the lower terminal of the fuse with its associated fittings.

To prevent external flashovers resulting from the presence of ionized air associated with such extreme voltage gradients, an electrostatic shield has been built into the tube structure. Figure 1*a* shows the voltage stress lines between the end of the arcing rod and the lower terminal. It is readily seen that very high voltage gradients are present at the fittings adjacent to the tube. The corona associated with such high-voltage stresses creates sufficient ionized air surrounding the tube to cause external flashover over the entire length of the fuse unit. Figure 1*b* shows the voltage-stress distribution with an electrostatic shield in the insulating tube. It will be observed that the maximum voltage gradient is now impressed on solid dielectric and not on the air adjacent to the fuse tube, so that external corona is eliminated.

A further requisite of the drop-out type of fuse construction, particularly for the voltages under consideration, is that the drop-out action must not start until the circuit is positively interrupted within the fuse unit. If the fuse unit should start to drop out before the current is interrupted, there will be arcing at the top contacts which would create sufficient ionized gases to cause flashover

To secure positive time delay between the time of fusion of the calibrated element and the initiation of the drop-out action, a construction has been adopted whereby the drop-out action is not initiated until the moving arcing rod has reached the end of its travel.

Figure 7. Oscillograms of interrupting tests on 69-kv fuse

(*a*). 240 amperes 66-kv restored voltage
(*b*). 1,950 amperes 66-kv restored voltage
(*c*). 15,300 amperes 66-kv restored voltage

Construction and Operation

A complete fuse consists of a fuse unit which is nonrenewable and is replaced by an entirely new unit after fault interruption and a fuse mounting which includes the necessary fittings to convert the fuse unit into a disconnecting unit. Figure 2 shows this assembly in the closed position.

The Fuse Unit

The new high-interrupting-capacity fuse unit consists of a short low-temperature calibrated element at the end of a solid conductor rod extending through a boric-acid-lined chamber, a copper tube for conducting current from the upper ferrule to the arcing rod through a modified form of tulip contacts and enclosing the operating spring which withdraws the arcing rod from the interrupting chamber, all enclosed in a lightweight Micarta tube with copper ferrules as shown in Figure 3.

The insulating tube is made from a rolled Micarta tube selected for high mechanical and impact strength, high dielectric strength, resistance to moisture absorption, and freedom from warping. The electrostatic shield at the lower end of the tube consists of copper foil rolled into the tube during fabrication in the same manner as used in the construction of high-voltage condenser bushings. This foil is electrically connected to the lower ferrule of the fuse unit. Copper ferrules are shrunk onto the fuse tube and then rolled.

The lower half of the fuse tube is lined with molded boric-acid blocks cemented in the tube with a moisture-resistant high-dielectric-strength cement. The diameter of the opening in the boric acid is a maximum at the bottom of the interrupting chamber tapering down to a diameter slightly larger than the size of the arcing rod at the top. The length of boric acid having maximum opening is chosen so that interruption of the maximum fault currents will take place when the arcing rod has traveled a distance sufficient to prevent severe voltage stress. Moderate fault currents are interrupted when the arcing rod has traversed the intermediate taper, and low currents are cleared when the arcing rod is drawn into the final taper. To insure that low fault currents corresponding to the minimum melting current of the lower rated fuse elements are cleared in the shortest possible arcing time, the arcing rod and the bore of the top section of boric acid are of smaller diameter than that of the rod and boric-acid blocks used for the high current ratings. The minimum current to be interrupted by a fuse will be, of course, dependent on its ampere rating.

An enlarged section at the top end of the arcing rod engages the flexible contact fingers which are part of the conductor tube to the top fuse-tube ferrule.

Figure 8. Oscillograms of short-circuit tests on 92-kv fuse

(a). 167 amperes, 88-kv restored voltage

(b). 3,600 amperes, 88-kv restored voltage

The contact surfaces are heavily silver-plated for low contact drop for the life of the fuse under all atmospheric and temperature conditions. A stainless-steel compression spring assures uniform and continuous contact pressure without binding. These contacts are so biased that the effort required to withdraw the contact from the fingers is only a small fraction of that exerted by the stainless-steel operating spring which is terminated on this enlarged section of contact rod.

The calibrated element in this new fuse is of the low-temperature type so that operation at or near full-load rating will not create temperatures that will dehydrate the boric-acid lining or impair the strength of the fuse tube. A high-strength strain element relieves the calibrated element of all spring tension.

When the calibrated element is fused by a fault current, the operating spring draws the arcing rod through the boric-acid arcing chamber. The heat of the arc decomposes the surface of the boric acid into water vapor and inert boric oxide. The blast of water vapor deionizes the arc path and effects interruption. The arcing rod, which is not rigidly connected to the operating spring does not stop when the spring reaches its fully closed position but continues on through the spring by virtue of its inertia until the end punctures a frangible disk in the top ferrule. A special spring washer stops the travel of the arcing rod by arresting its enlarged section. This washer also functions to retain the arcing rod and prevent it from dropping back into the tube. The rod projecting from the top ferrule initiates the drop-out mechanism. It is obvious that the drop-out action cannot start until the arcing rod has traversed the entire length of the interrupting chamber which insures that all fault currents are interrupted before the tripping out action occurs.

The Fuse Mounting

The fuse-unit fittings which comprise

Figure 9. Oscillograms of short-circuit tests on 115-kv fuse

(a). 145 amperes, 110-kv restored voltage

b). 4,400 amperes, 110-kv restored voltage

Figure 10. Oscillograms of short-circuit tests on 138-kv fuse

(a). 180 amperes, 132-kv restored voltage

(b). 5,300 amperes, 132-kv restored voltage

Figure 11. Single-pole unit, 92 kv, 200 amperes, with fuse. Unit in dropout position

a part of the fuse mounting are shown clamped onto the fuse tube in Figure 4. These fittings, comprising a hook eye for the top end of the fuse unit so that the fuse unit can be used as a disconnecting switch and a hinge casting for the lower end of the fuse tube that incorporates a lifting eye to facilitate the removal and replacement of the fuse with a standard hook stick, are readily removed from a blown fuse unit and placed on a new unit. These fittings are so keyed to the fuse unit that the correct fitting can fit only on its end of the fuse unit and assures perfect alignment of the fittings.

The fuse mounting proper consists of a double steel channel base for the higher voltages, and two insulator columns with latch castings and hinge castings mounted thereon. The top contact and trip-out mechanism are enclosed in a sleetproof housing, as shown in Figure 5. Current is conducted from the terminal to the pivoted latch casting by means of a flexible copper shunt. A powerful stainless-steel compression spring insures adequate contact between the latch casting and the hookeye casting clamped to the top ferrule of the fuse unit. It will be noticed that the force exerted by this spring puts the fuse tube in compression and thus avoids warping of the fuse tube from continuous cantilever stress. The drop-out trigger is pivotally mounted on the latch casting and bears on a projection within the sleet hood. Tests have shown that the kinetic energy of the moving arcing rod is more than ample to insure positive tripping regardless of alignment, variations in length of the fuse unit, or any possible friction that might be due to weathering or corrosive atmospheres.

The construction of the hinge is shown in Figure 6. Current is conducted from the fuse unit to the terminal pads by copper alloy leaf springs. The lower or lifting eye casting on the fuse unit and the hinge casting are so designed that the fuse unit is positively guided throughout the disconnecting or closing-in movements. The fuse unit can be removed from the mounting only when the fuse unit is in the 180°-open position. This arrangement also provides for the lower insulator stack taking the entire upward reaction resulting from gas blast on high current interruption thus insuring proper action of the drop-out mechanism. Below the hinge casting is a simple leaf spring bumper to absorb the energy of the falling fuse unit without overstressing the insulator column. This arrangement was chosen in preference to a friction brake because of its simplicity, its reliability under all atmospheric conditions, and the amount of energy to be absorbed in braking the fall of the long fuse unit.

Test Results

Complete interrupting tests have been made in the high-power laboratory covering the range from the minimum melting current of the smallest fusible element up to destruction of the fuse. Test-circuit conditions were modified from a very severe circuit where voltage-recovery rates correspond to a natural frequency of approximately 7,000 cycles per second to circuits with a very low voltage-recovery rate corresponding to natural frequencies as low as 800 cycles per second.

The majority of the interrupting tests were made with full line-to-line voltage impressed across a single fuse unit with the lower terminal at ground potential. Other tests were made with line-to-line voltage across a single fuse with the neutral grounded at the fuse mounting base. Also the fuses have been tested at line-to-neutral voltages to determine the upper current limit at reduced voltage.

Representative oscillograms of interrupting tests are shown in Figures 7 to 10.

The new assembly for carrying current through the fuse unit has been thoroughly tested for reliability on all values of fault current up to those which cause destruction of the fuse unit. In addition, high-current short-duration faults that did not blow the largest fuse rating were applied. In no case was there a failure of these parts to perform satisfactorily. In the case of the high currents applied momentarily there was no welding or damage that might cause failure to operate on subsequent faults. Prolonged temperature-rise tests indicate the complete adequacy of all current carrying parts and contacts. The silvered contacts on the fuse rod within the fuse unit carried full rated current with an unusually low temperature rise.

High-speed moving pictures were used extensively during interrupting tests as a check on the operating sequence of the drop-out action and for checking the time required to trip out. These moving pictures were of invaluable assistance in locating the cause of flashovers in the early designs. They also presented an accurate picture of the size and shape of the cone of gases evolved from the fuse, thus enabling the designer to design an opening so that gases would not be deflected in such a way as to cause flashover of adjacent apparatus.

Application

The selection of a high-voltage fuse for isolation of faults in potential transformers does not require any special precautions, as the fuse can operate only on a fault in the connected equipment. When high-voltage transmission system is tapped to obtain small blocks of power, it is recommended that high-voltage fuses be connected as close to the power transformer as practicable and that sec-

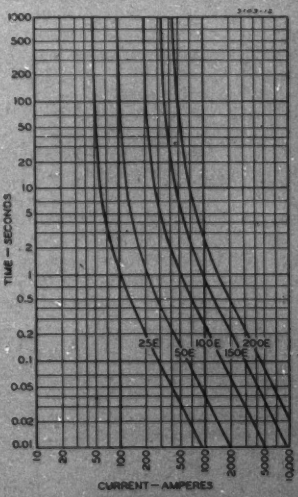

Figure 12. Melting time–current curves for representative fuse ratings

Subcenter Switching Systems for Teleprinter Tie Lines

F. L. CURRIE
MEMBER AIEE

Synopsis: One of the means used by the telegraph companies for improving the speed of their service is the provision of printing telegraph circuits between their central offices and the offices of many users of the telegraph. In the beginning, circuits of that type were restricted to patrons whose volume of telegraph business and proximity to a central office justified the expense involved in their installation and maintenance. A large part of that expense, when the patrons are located remotely from the central office, is in the line-wire costs.

This paper describes an automatic switching means for economically enabling a large number of patrons, when grouped in one locality, to be furnished printing telegraph service with a distant central office by causing them to share the use of a comparatively small number of line wires between that locality and the distant central office.

This paper also cites benefits gained from present installations.

AMONG the methods used by the telegraph companies during the last two decades for improving the speed of their service has been the provision of printing telegraph circuits between their central offices and the offices of many users of the telegraph service. That type of accommodation employes the use of the printing telegraph mechanisms, variously termed "teleprinters," "teletypewriters," or "teletypes," and is known in the Western Union Telegraph Company as teleprinter tie-line service.

Because of the expense involved in providing and maintaining the equipment and line wires essential to that service, it has been restricted to those patrons whose proximity to the central office and volume of business warranted the expenditure. Therefore, many substantial users of the telegraph service, because of their remoteness from a central office, had to be denied the advantages of teleprinter tie-line service because of the high line-wire costs involved. In some cases even groups of patrons were in that category.

The Western Union Telegraph Company undertook several years ago the development of a means for bringing those groups of remote patrons within the scope of teleprinter tie-line service by reducing the amount of line wire required.

Long experience in serving patrons over teleprinter tie-lines through central-office concentrators[1] has shown that most of those lines are in use only a small part of the time, and that the probability of any large percentage being used at any one time is small. That knowledge of their normal requirements led to the development of a remote controlled switching means for enabling a large number of patrons, grouped in one locality, to share the use of a comparatively small number of line wires to a distant central office. In that manner the necessary line-wire savings are effected to make economically feasible the extension to many more patrons the faster service afforded by teleprinter tie-lines.

The switching means, termed "subcenter," is designed to be installed in the same locality as the group of patrons, to be connected to each patron's office by an individual line wire, termed "patron's line," and to be connected to the central office by only as many line wires, termed "trunks," as the peak volume of business at any one time requires. An installation containing a subcenter is termed a "subcenter switching system."

Description

Equipment

The equipment required for a subcenter switching system is divided into

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ondary circuit breakers or other protective devices be used to interrupt all secondary faults. The high-voltage fuses will then operate only on faults in the power transformers. For such applications the fuse rating selected must provide adequate time for co-ordination with the relays controlling the secondary breaker. The proper rating should be determined from the time–current characteristic curves of the fuses and will usually exceed four times the full-load current of the transformer.

The addition of fuses on a system to isolate faults in equipment will enhance the reliability of the entire system by the rapid interruption of short circuits that would otherwise result in breaker operations or even in ground that might be difficult to locate.

At the higher transmission voltages it is generally not advisable to use fuses to protect even a small tap line that is exposed to lightning, unless the nature of the load is such that an outage caused by fuse operation can be tolerated.

Conclusions

Numerous interrupting tests, covering the complete range of fault currents under all possible circuit conditions, show that these new fuses are entirely satisfactory for application to important high-voltage transmission circuits. Their interrupting ability is such that they may be safely applied to systems approximating 1,000,000-kva short-circuit capacity at 66 kv through 132 kv.

The positive time-delay drop-out action provides an air gap in the circuit after operation which has a breakdown voltage ten per cent greater than the breakdown voltage of the basic impulse level (BIL) insulator columns. These fuses may therefore be applied on hydroelectric transmission circuits where sudden interruption of load currents may cause overshoot of recovery voltages.

These new high-interrupting-capacity power fuses can now be applied to important high-voltage transmission systems to rapidly clear faults in connected equipment, thereby enhancing the reliability of the complete system. They also provide an economical means for tapping off small blocks of power from high-capacity systems.

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three general groupings, one for the subcenter, one for the central office, and one for the patron offices.

Subcenter

The subcenter switching equipment consists primarily of electrically operated multicontact relays and multicontact switches mounted either on racks or in cabinets, and in their assembled form termed "subcenter switching units." The relays are used primarily for control and signaling purposes, and the switches for making connections between the trunks and the patron tie-lines.

The switches are of the well-known Strowger type of two-motion and rotary switches. The two-motion switch is used to select the desired patron's line wire when a call is originated at the central office, and the rotary switch is used to seek the patron line wire when a call is made from the patron's office. The corresponding contacts of the contact banks which form a part of the two-motion and rotary switches are connected in multiple so that all of the patron tie-lines are available to all of the switches. The wipers of each switch are associated with a group of equipment individual to one trunk and complete the connections between that equipment and the equipment associated with the patron's line.

Figure 1. Small-size subcenter switching unit for ten patron tie lines and three central-office trunks

Three types of trunks, termed answering, calling, and combination trunks, are used for connecting the subcenter to the central office. The "answering trunks" are the trunks over which connections are made only when the calls are originated at patron offices; the "calling trunks," only when the calls are made at the central office; and the "combination trunks," when the calls are made at either the patron offices or the central office. The combination trunks, with the exception of the smallest size installations, require as much equipment in the subcenter switching units as an answering and a calling trunk combined, and, therefore, but few of them are used in any one installation. When installed, they are included primarily as overflow trunks, since they function as either answering or calling trunks.

Central Office

The central office equipment may consist either of a group of operating tables, termed "subcenter operating tables," with each table connected directly to a trunk, or of existing teleprinter concentrator equipment.

The subcenter operating tables are classified as "answering," "calling," or "combination," the classification depending on the type of trunk with which they are to be used. The equipment required is basically the same for all of them. In general, it includes a teleprinter, a signal lamp, control relays, and in the case of a calling or combination trunk, a dialing unit. The teleprinters, signal lamps, and dialing units are mounted on the table tops and the control relays in a metal box underneath.

The subcenters also are designed to direct the calls of all patron offices to the central office over as few trunks as possible by always switching the patron lines to the lowest numbered idle trunk. That feature enables them also to perform the functions of an automatic concentrator for the central office. Although they function as concentrators themselves their central-office trunks are often connected to concentrators at the central office for converging the business of one subcenter with that of another, and also with that of the patron tie-lines connected directly to the concentrator.

The equipment of teleprinter concentrators consists, essentially, of turrets, control relays, signaling lamps, and operating tables. Each turret contains a large number of jacks, and one is located convenient to each operating table. Each turret jack is multipled to the corresponding jack of all of the other turrets, and each of the multiple connections is connected to a separate incoming line which may be either a teleprinter tie-line or an answering trunk from a subcenter. Thus, all of the directly connected patron tie-lines and the answering trunks from the subcenter are connected to all of the turrets so that any line or trunk can be worked from any turret.

Each operating table of the concentrator contains, primarily, a teleprinter and a circuit from the teleprinter through control relays to a cord and plug located at a turret. As many operating tables are provided as are likely to be required at any one time. Connection is made between an operating table and a desired patron's line or answering trunk from a subcenter by inserting the plug of that operating table in the proper jack of the turret.

Each of the calling trunks from a subcenter is connected directly to one of the operating tables of the concentrator and can be worked only from that operating table. A dialing unit containing a dial, similar in general appearance to the dials used in automatic telephone systems, and a control key switch, is added to the equipment and circuits which normally form a part of those operating tables. The key switch is used for adapting the operating table to work with either its directly connected calling trunk from a subcenter or with any line connected to the turret jacks, and the dialing unit is used to select the line of any of the patron offices connected to the subcenter by controlling the selecting mechanism of that equipment.

Each combination trunk from a subcenter is connected both to a multipled jack circuit in the turrets and to one of the operating tables, since it functions as either an answering or calling trunk.

When the combination trunk is in use as an answering trunk, it is automatically disconnected from the operating table to which it is normally connected, and, when it is used as a calling trunk, it is automatically disconnected from the turrets. Also, when it is used as a calling trunk, the equipment associated with it at the subcenter automatically busies it to all patron calls. Hence, safeguards are included to prevent interference to service from any attempt to use this circuit for its two functions at the same time.

Patron's Office

The equipment at the patron's office consists, primarily, of a teleprinter, a signal lamp, a polar relay, and a teleprinter

operating table. That is the same teleprinter tie-line equipment which is used for operation with concentrators. The signal lamp is controlled by the polar relay and serves to advise the operator when the central office calls.

Standard Systems

Each of the first subcenter switching systems was devised for a specific installation, but the later ones were designed as standard systems for general usage. The latter differ from the first in flexibility, in the ultimate sizes of the installations, and in some details of circuit design. They were designed for three different sizes of installations, small, intermediate, and large, so that an economically feasible one would be available for any probable requirement.

Small System

The smallest of the systems enables groups of ten patrons to be served by a remote central office over three trunks. The subcenter switching equipment is housed in a single cabinet as illustrated in Figure 1.

Combination trunks, only, are provided between the central office and the subcenter, and the same equipment at the subcenter is used for calls originating at either the central or the patron's office. This differs from the intermediate and large systems, described later, in that those systems require two sets of equipment at the subcenter, one calling and one answering, for each combination trunk.

Provision is made in the design of the units for connecting two of them together in a single installation to provide for 20 patrons and six trunks when the requirements grow beyond the capacity of one unit.

Intermediate System

The next, or intermediate, size system is designed to serve groups of 25 patrons over eight trunks to the central office. The equipment of the subcenter, like that of the small system, is housed in a single cabinet (Figure 2).

Normally, three calling and five answering trunks are provided between the subcenter and the central office. Combination trunks may be provided by connecting together, at the subcenter, the equipment of one calling and of one answering trunk for each combination trunk desired. Hence, each combination trunk provided reduces by one the total number of central-office trunks that can be accommodated by the subcenter unit. A maximum of three combination trunks may be provided in this manner for each unit.

Provision also is made in the design of the subcenter switching units of this system for connecting two of them together in a single installation to double the capacity to 50 patrons, six calling and ten answering trunks.

Large System

Each of the small and intermediate systems requires that all of the patrons be connected to the one subcenter in order to share the trunks to the central office. The large system, in addition to serving a much larger number of patrons, also provides for serving the trunks of as many as seven smaller size subcenters. Thus, the large system may consist of one main subcenter serving 200 patron tie-lines and as many as seven tributary subcenters, each of which may serve 25 patron tie-lines, combined into a single large system serving a total of 375 patrons. The main subcenter, to which the central-office trunks are terminated, is termed the "subcenter," while the seven tributary subcenters are termed "sub-subcenters." The sub-subcenters may be either the 10 or the 25 patron size already described. Combining a large number of patron tie-lines in one system in that manner considerably reduces the number of trunks that would be required between the locality of the patrons and the distant central office if those patron tie-lines were served by several smaller systems. The plan of this system is illustrated by the diagram of Figure 3.

The equipment of the subcenter is assembled in nine units (see Figure 3). Two of the units contain that portion associated directly with the calling trunks; two, that portion associated directly with the answering trunks; one, that portion associated directly with the sub-subcenter answering trunks; and, four, that portion associated with the directly connected patrons. Each calling trunk unit provides for eight calling trunks to the central office and ten sub-subcenter calling trunks; each answering trunk unit, for 16 answering trunks to the central office; each patron tie-line unit, for 50 patron tie-lines; and, the sub-subcenter answering trunk unit for 35 sub-subcenter answering trunks. Hence, an installation equipped for maximum capacity operation provides for 16 central-office calling trunks, 32 central-office answering trunks, 200 directly connected patron tie-lines, and 55 sub-subcenter trunks.

All of the patrons, regardless of whether they are connected to the subcenter directly or by sub-subcenter trunks, share the use of all of the central-office trunks.

Figure 2. Intermediate-size subcenter switching unit for 25 patron tie lines and eight central-office trunks

The trunks between the subcenter and the central office also may be converted to combination trunks by combining the equipment in the subcenter of one calling and of one answering trunk for each combination trunk desired. A maximum of 16 combination trunks can be obtained in that manner.

Operation

All of the subcenter switching systems mentioned in this paper operate fundamentally in the same manner.

Calls can be originated from either the central or any patron's office, but connections can be completed only between the central and a patron's office. No provision is made for making connections between any two patron offices.

After a connection is made, transmission may be carried on in either direction until the connection is released, regardless of which office initiated the call. The connections normally are released only from the central office.

The operations required at either the central or the patrons' offices for causing the subcenter switching equipment to effect a connection are so simple that no special training of the personnel is necessary for proper operation.

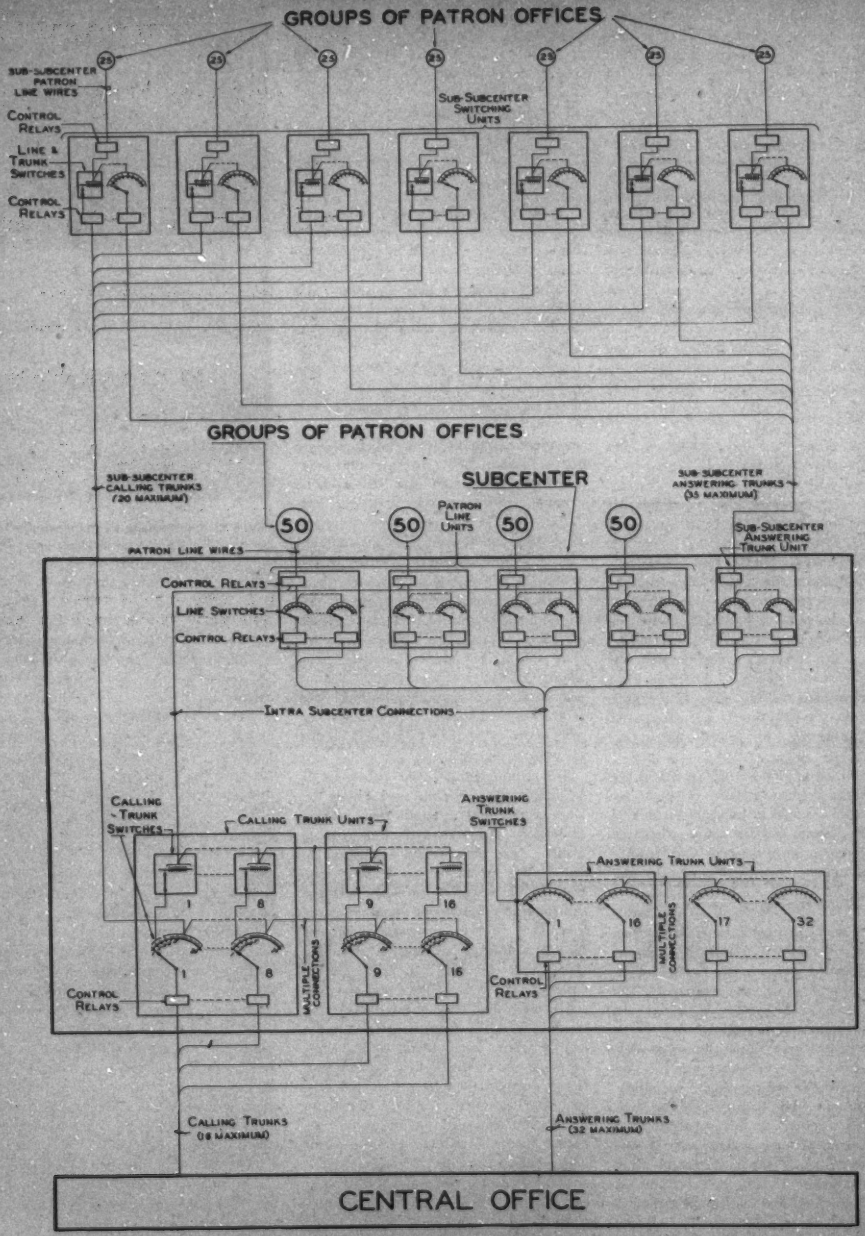

Figure 3. Diagram showing plan of large subcenter switching system

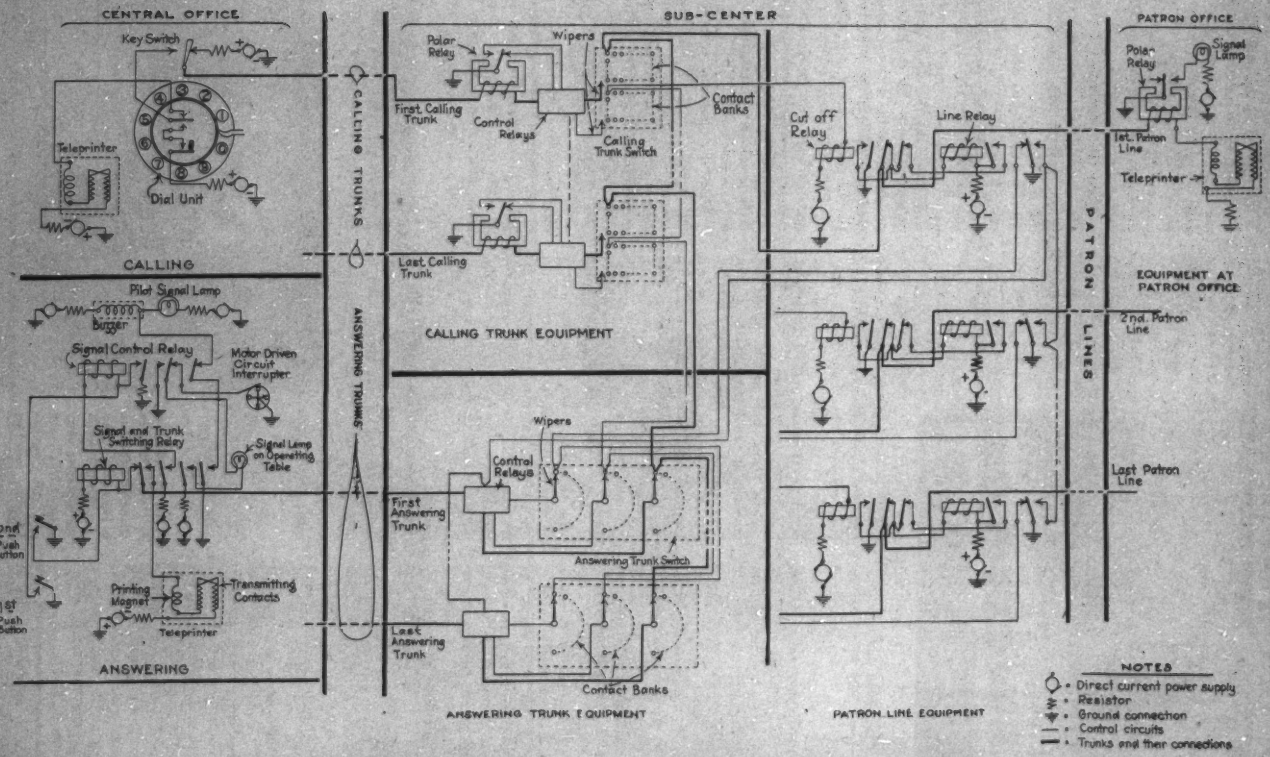

Figure 4. Simplified schematic diagram of the circuit and equipment used in a typical subcenter switching system

Figure 5. View of switching equipment at Newark for large-size subcenter-switching system

Figure 4 is a simplified schematic diagram of the circuit and equipment arrangements used in a typical subcenter switching system. The trunks are shown terminated on individual tables in the central office. Many details of the control circuits and relays are omitted from the diagram for reasons of simplicity.

A call originated at any patron's office is initiated by the patron's operator opening, momentarily, the normally closed line between her office and the subcenter by depressing any one of the keys of her teleprinter keyboard. The opening of the line allows a normally operated relay, termed "line relay," connected in series with the line in the subcenter switching unit, to release and lock itself released.

The release of that relay causes the wiper contacts of the switch associated with the lowest numbered idle answering trunk, through the medium of control circuits and relays, to seek the patrons' line containing that relay by advancing, step by step, over the contacts of its contact bank.

When that patron's connections are found, control circuits and relays associated with the respective switch and the patron's line function to disconnect ground from the trunk, and power from the patron's line, and after a brief lapse of time (about 0.3 second), to connect the trunk and the patron's line together. The brief interval of time between the removal of ground from the trunk and the connecting of the trunk to the patron's line wire constitutes a sufficient opening of the trunk to allow a normally operated relay whose winding is connected in series with the trunk at the central office to release and operate the central office signaling equipment.

When the answering trunks are connected directly to individual tables at the central office, the release of the relay, termed a "signaling and line switching relay," not only signals the operator but also connects the central-office teleprinter to the trunk and reverses the polarity of the power applied to the trunk from positive to negative.

Both visual and audible signals are provided at the central office. A pilot lamp and buzzer, conspicuously located, give a continuous alarm, and a signal lamp, mounted on the table to which the call is directed, flashes repeatedly until an operator presses a push button on the table top for operating the signal control relay. Those signals advise the operators that a new call has been received, and the push button is pressed when the call is answered. The operation of the signal control relay silences the buzzer, extinguishes the pilot lamp, and causes the signal lamp on the table to glow steadily, instead of flashing, and to continue glowing as long as the connection is allowed to remain. This alarm signaling arrangement is used to insure that all calls are given prompt attention, and the continuous glowing of the signal lamp is provided for supervisory purposes.

The reversal of the power applied to the trunk, from positive to negative, causes a polar relay, connected in series with the trunk at the subcenter, to reverse its armature and prepare the subcenter switching equipment for releasing the connection when the transmission of business is completed.

When the transmission is completed, the central-office operator presses a second push button, which reoperates the signaling and line switching relay. The operation of that relay transfers the trunk from the teleprinter and power of negative polarity to a circuit through its own winding and power of positive polarity. It also opens the circuits to the signal lamp and the signal control relay winding causing the lamp to be extinguished and the relay to release. The reversal of power to the trunk from negative to positive causes the armature of the polar relay, whose winding is connected in series with the trunk in the subcenter, to reverse to its original position and release the connection. The trunk is then available for connection to another patron's line wire.

When the answering trunks are terminated at a teleprinter concentrator, the opening of the trunk at the subcenter causes only a signal to be given at the central office for identifying the trunk and attracting the attention of the operator. The reversal of power polarity to the subcenter, from positive to negative, is effected by the operator's inserting the plug of her operating table circuit into the proper jack of the turret. This operation transfers the trunk from its normal idle connection and positive polarity of power to the operating table circuit and negative power.

When transmission is completed, the plug is removed from the jack, causing the power applied to the trunk to be changed to positive, which is the idle condition

Figure 6. Section of the Western Union central office in New York. This view shows some of the subcenter operating tables used with the Newark subcenter switching system

polarity. Hence, the plug and jack, with their associated relays, perform the same functions at the central office when concentrators are used as the signaling and trunk switching relay and the push buttons when individual tables are used.

Calls are initiated at the central office by reversing the power applied to the trunk from positive to negative by operating a key switch and by dialing the numeral assigned to the desired patron office in the same manner as the digits of dial telephone numbers are dialed. The reversal of power polarity prepares the subcenter equipment, associated with the calling trunk, for responding to the dial pulses and for advancing the wiper contacts of the switch to the contacts of its bank associated with the desired patron's line.

When the proper contacts are reached, the patron's line is first tested automatically at the subcenter to determine whether it is idle or is busy. If it is busy, an automatic busy-signal transmitting device sends a busy signal over the calling trunk to the central-office operator. If it is idle, control relays at the subcenter associated with the trunk and the dialed patron's line function to disconnect the patron's line from positive power at the subcenter and connect it to the trunk line which, at that time, has power of negative polarity applied at the central office. This reverses the direction of current over the patron's line and causes a polar relay connected in series with the line at the patron's office to operate and signal the call. The patron's operator answers the call with her teleprinter keyboard.

When transmission is completed, the central-office operator restores the lever of her key switch to its normal idle position which restores the central-office circuits and equipment to their idle condition, and reverses the polarity of the power applied to the trunk for releasing the connection at the subcenter. The trunk then is available for connection to another patron's line.

Several interesting auxiliary features are contained in the switching units. One of them is a means for automatically wiping out false calls on patron's lines which might result in the event of a temporary interruption of the local power supply to the subcenter switching units. Since power is furnished the patron line wires from the subcenter switching units, any interruption of that power results in an interruption of the current flow over the line wires. Any interruption of the current flow over the patron's line wires allows the line relays of all the patron lines at the subcenter to release in the same manner as they do for bona fide patron calls. If automatic preventive measures were not included in the design, each patron line wire would be switched to the central office as fast as answering trunks became available until all had been connected to and released by the central office. The false call wipe-out feature functions after each power failure to prevent all switches associated with answering trunks from operating, to re-establish the patron line-wire relays at the subcenter to their normal idle operated condition, and then to allow all switches to operate normally again.

Another interesting feature is a provision for "busying" the equipment at the subcenter of any answering trunk to all new calls by opening the answering trunk circuit. That enables the central-office attendants to remove any trunk from service for maintenance or for any other reason, and it also automatically prevents the connecting of a patron's line to an open trunk.

Installations

Examples of the benefits which subcenter switching systems can render are afforded by the installations which have been in service for several years between patrons in Oakland and the central office in San Francisco, patrons in Beverly Hills and the central office in Los Angeles, and patrons in Newark and the central office in New York City.

The Oakland–San Francisco system was designed to enable the central office in San Francisco to serve 50 patrons located in Oakland over 16 submarine cable conductors (six calling and ten answering trunks) across San Francisco Bay. All trunks were terminated in an existing teleprinter concentrator at the central office in San Francisco.

The Beverly Hills–Los Angeles system utilizes one of the 25 patron subcenter switching units previously described and shown in Figure 2. All trunks are terminated in an existing teleprinter concentrator at the central office in Los Angeles. This installation relieved an acute wire shortage caused by furnishing direct teleprinter tie-line service between those points to 15 patrons, and at the same time provided accommodations for extending the service to ten more such patrons.

The Newark–New York City system was the first of the larger systems designed and installed. Though the installation as now equipped accommodates only 150 patrons, the design provides for adding equipment to increase this number to 200 whenever the need for it develops.

The equipment of the subcenter, which is located in Newark, is housed in five racks as shown in Figure 5, and these racks are enclosed in an air-conditioned room for protecting the equipment from dust. The three similar racks shown in the foreground are the patron line units, the fourth is the calling trunk unit, and the fifth is the answering trunk unit. One patron line unit has a capacity of 50 patron tie-lines; one calling trunk unit, ten calling trunks; and one answering trunk unit, 36 answering trunks.

The system, at present, is served by 27 trunks, two of which are calling, five are combination, and 20 are answering. These trunks are terminated on individual tables in the central office in New York. Figure 6 is a view of that portion of the central office in New York containing most of those tables.

The first two installations, the Oakland–San Francisco and the Beverly Hills–Los Angeles, effected substantial savings in line wires and increased the capacity of the Western Union to furnish more of the same type of service between those points.

The Newark–New York installation greatly reduced the cost of operation by eliminating one relaying, or retransmission, of the patron business at Newark.

In the past, the business was received in the Newark central office and most of it was retransmitted to one of the few large central offices connected to it, for further retransmission to its destination.

At present that part of the business destined for New York is handled directly, and the rest is retransmitted either to its destination or to a point much closer than was possible before, since the New York office is provided with direct connections to many more cities than was the Newark office.

The benefits anticipated from the use of subcenter switching systems have been fully realized in the installations made thus far.

Ease of operation, improved speed of service, saving of line wires, and in some instances, such as the Newark case, the reduction of operating costs, are the factors which make this development promising for future use in the telegraph industry.

Reference

1. A Printing Telegraph Concentrator, W. B. Blanton. AIEE Transactions, volume 50, 1931, pages 414–25.

Aircraft Circuit Breakers

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FELLOW AIEE

Synopsis: Airplane circuit breakers are recognized as important units in the electrical systems of military aircraft. The design of such circuit breakers can be combined with switching and contactor functions. This makes possible the use of well-developed switch and contactor structures.

The design of such circuit breakers must provide for operation under the very exacting requirements of military aircraft service.

The principal function of both manual and remote-control circuit breakers is to provide short-circuit protection. There is some question as to the desirability of motor protection for military aircraft. Many motor functions are vital to the operation of the aircraft, and it may be better to operate the motor to destruction rather than to stop at a safe temperature or load value. Where motor overload protection is desired, it is necessary to correlate circuit-breaker and motor characteristics. Both manual and remote-control circuit breakers can be made to provide for holding the circuit closed in emergency to "force" the motor or other equipment.

ELECTRICAL operation and control have contributed largely to the effectiveness of today's military aircraft. It has been necessary to develop new types of electrical equipment to meet the special requirements of this service. Minimum size and weight are of extreme importance.[1] Control devices must operate in any position, must withstand high rates of acceleration and retardation, must operate in ambient temperatures of −50 to 200 degrees Fahrenheit, must operate at high altitude with rarefied atmosphere, and must withstand severe vibration.

Extensive electrical power systems are required for these military aircraft, particularly for the large bombers. Maximum reliability for the various circuits for these power systems is of unusual importance. Any part of the electrical power systems may be damaged in battle. As much of it as possible should remain available. It should be possible to restore power to any circuit as soon as a fault is cleared. Airplane-type circuit breakers are the logical answer to these problems.

Twenty-four volt d-c power with stand-by storage battery is the most extensively used power system for United States military aircraft. The lower voltage as compared to industrial power reduces the interrupting problem for circuit breakers but increases current values for a given power rating. Short-circuit faults in such a system may result in current of from 1,000 to 3,000 amperes. Such service presents serious contact problems.

These contact problems have been largely solved in the development of aircraft manual switches and contactors. One solution to the aircraft-circuit-breaker problem, therefore, is the addition of thermal trip units to these aircraft switches and contactor. Such an arrangement has a number of obvious advantages. The manual switches and contactors can be used for their normal service. The same mounting arrangements are available. Repairs and replacements are simplified. This type of design is a dual purpose one in which circuit or overload protection has been added to the normal switching or contactor function. Our discussion here will be limited to the features of circuit or overload protection.

The thermal trip units must be designed with special consideration for the service requirements of military aircraft. Their tripping values must not be appreciably affected by acceleration of $10g$ (where g is the acceleration of gravity) or more, or the effect of severe vibration. They must not change in rating in altitude from sea level to approximately 40,000 feet. These results can be accomplished by proper design.

Manual Circuit Breakers

The manual-type circuit breaker consisting of an airplane-type switch with bimetal thermal trip provides both circuit protection and switching functions. The X-ray pictures, Figures 1, 2, and 3, show the general construction of one such airplane circuit breaker. The switch mechanism provides make and break contacts operated by a toggle lever. This toggle lever may be provided with a luminous or fluorescent end. The trip unit is of the bimetal type. The bimetal latches a spring-actuated trip member. When the current through this bimetal trip unit exceeds a predetermined value for a sufficient length of time, the bimetal trips the latch and causes the circuit breaker to open its contacts. The contacts are reset by returning the toggle lever to the "on" position.

A thermal trip unit, in which the current flows through the bimetal, has a relatively sharp knee in the tripping-time curve. This is favorable to the protection of the circuit, as the wiring cable likewise has but little thermal capacity and reaches its maximum permissible temperature in a relatively short time. The relationship between the time re-

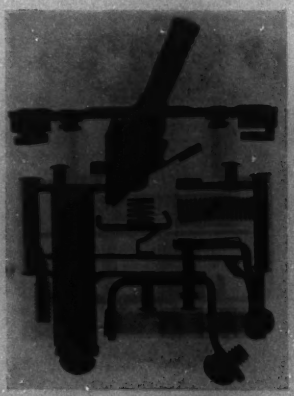

Figure 1. Manual circuit breaker
Contacts open, thermal trip unit latched

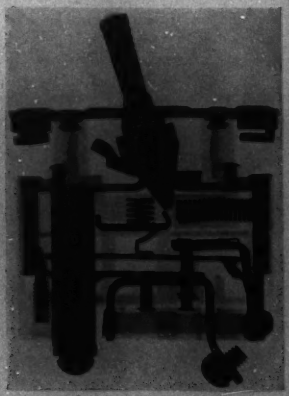

Figure 2. Manual circuit breaker
Contacts closed, thermal trip unit latched

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quired for the cable to reach a temperature of 90 degrees centigrade as compared to the tripping time of a circuit breaker with a tripping temperature of 150 degrees centigrade, is shown in Figure 4.

Short-circuit protection is the principal function of the manual circuit breaker. The amount of short-circuit current is determined by the circuit. High-capacity circuits will generally have higher short-circuit currents than low-capacity circuits. This is illustrated by the accompanying table which shows standard manual-circuit-breaker ratings and short-circuit test currents.

Table II of Army Navy Aeronautical Standard AN-C-77, February, 1943

Breaker Rating (Amperes)	Short-Circuit Load (Amperes)
5	1,000
10	1,000
15	1,500
20	1,500
25	2,000
35	2,500
50	3,000

The service requirement for aircraft circuit breakers differs in other particulars from those used in industry. Some of the applications make it desirable to "force" operation of the equipment even though the motors may seriously overheat. Specifications, therefore, require the nontrip-free type of circuit breaker. This is based on tripping of the circuit breaker to protect the circuit and equipment in case of faults, yet permitting the operator to "force" the motors, in case of emergency, by holding the circuit breaker in the closed position.

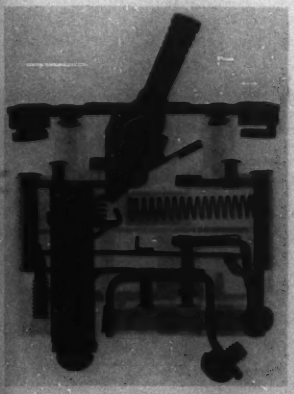

Figure 3. Thermal trip unit tripped, contacts open

Remote-Control Circuit Breakers

There are some applications, particularly on the larger military aircraft, where it is desirable to have the circuit breaker at a location remote from the point of control. Such installation reduces the amount of heavy wiring, thereby reducing the important element of weight. The reduced amount of heavy wiring further tends to increase reliability, because of damage from enemy fire.

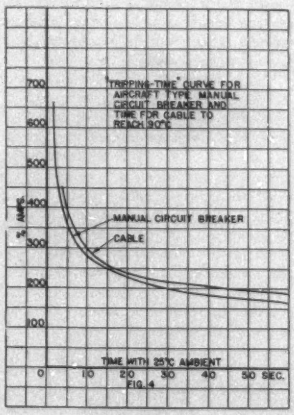

Figure 4

Circuit protection is the primary function of the remote-control circuit breaker. It is also possible to obtain motor protection, that is, to add the overload function to that of contactor and circuit breaker, making a triple-purpose device.

There is some question as to the desirability of motor protection for military aircraft. Many motor functions are vital to the operation of the aircraft, and it may be better to operate the motor to destruction rather than to stop at a safe temperature or load value. The following discussion, however, pertains to those applications where motor protection may be desired.

A remote-control circuit breaker consisting of an airplane-type contactor with thermal trip unit is shown in Figure 5. This combination can be obtained in the various standard sizes of contactor as used for airplane service, that is, 50-ampere, 100-ampere, and 200-ampere ratings. These airplane contactors provide the high interrupting capacity (3,000 amperes) and freedom from welding of contacts as required for circuit-breaker service.

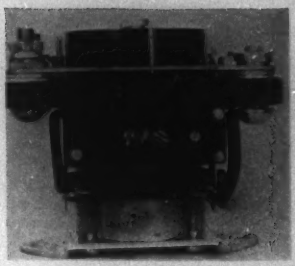

Figure 5. Remote-control circuit breaker

The thermal trip unit for these remote-control circuit breakers is shown in the X-ray photographs of Figures 6 and 7. This provides quick make and break pilot-duty contacts operated by a bimetal trip member. The contacts are insulated from the bimetal trip member by a small bakelite operating pin. The bimetal carries all or part of the main circuit current. The different ratings are obtained by the use of shunt elements which are an integral welded unit with the bimetal.

It is well established that the tripping temperature of an overload device should approximate the danger temperature of the equipment to be protected. For military aircraft it is desirable to operate to maximum capacity to avoid unnecessary weight. Class *A* insulation will permit of operation at temperatures of 125 degrees centigrade. This is recognized in the Underwriters' Laboratories standard on industrial control for built-in cycling overload motor protection.

The heating of any motor is, in general, proportional to the losses in the motor. It is, therefore, possible to determine an approximate heating curve for a motor if

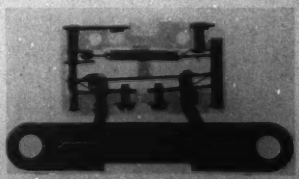

Figure 6. Remote-control circuit-breaker thermal trip unit

Contacts closed

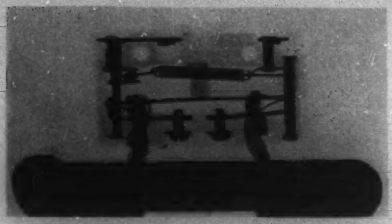

Figure 7. Remote-control circuit-breaker thermal trip unit

Contacts open

we have the efficiency curve and know the temperature rise at some particular loading. Such a study based on performance curves for a two-horsepower aircraft-type motor is shown in Figure 8.

From the heating curve for the motor we can readily determine a load curve for a range of ambient temperatures. This is based on the assumption that the final temperature of the motor will equal the sum of the ambient temperature and temperature rise for a given load. The proper trip temperature, for the thermal trip unit, is readily determined from this curve. Figure 9 shows motor load and thermal unit tripping-current curves. The motor load curve is based on a maximum winding temperature of 125 degrees centigrade and the curve for the thermal trip unit is based on trip temperature of 120 degrees centigrade.

The use of glass-insulated motor windings will of course permit of higher motor temperatures. Such motors require higher tripping temperature for overload protection. This is reflected to some extent in *AN-C-77* specifications which indicate an approximate tripping temperature of 155 degrees centigrade.

For motor protection it is necessary to provide a large number of ratings. These ratings should be spaced not more than ten per cent. If we protect the motor for a predetermined maximum temperature, it will be necessary to overprotect an amount equal to the spacing between ratings. This results in a corresponding loss in motor capacity.

Many aircraft motor applications are of the intermittent-duty type. The greatest need for motor protection on such application is protection against locked rotor. In order to determine such motor protection it is necessary to have the corresponding motor data. These include locked rotor current and the maximum time which the motor will permit of this current without exceeding the maximum permissible temperature. This maximum temperature may occur in either the field or armature windings. Many of these intermittent-duty applications are such that if the motor will operate at all, no further protection is needed. For such applications the remote-control circuit breaker provides motor protection equal to that which could be obtained with built-in overload protection. The remote-control circuit breaker provides quick reset for such applications, whereas built-in overload protection depends upon cooling of the motor and has a much longer reset time.

Circuit-breaker standards specify ratings which will cause tripping at 25 degrees centigrade from 115 per cent to 138 per cent of the established rating. This is primarily intended for circuit protection and to insure that rated load will not cause tripping. This method of rating must be understood when making applications of remote-control circuit breakers for motor protection. These ratings, however, can be readily translated into the usual overload ratings which provide that the overload unit trip under all conditions in a 40 degrees centigrade ambient. The recognized standard of accuracy for overload protection is a tolerance of +0 to −10 per cent.

Remote-control circuit breakers for many military aircraft applications should be arranged for "forcing" the motor in emergencies. It is also desirable to indicate tripping of a remote-control circuit breaker at the control point. These functions can be obtained by control circuits as shown on Figure 10. This circuit requires but a single control wire with grounded return. The use of the two-way momentary contact pilot switch provides six operating functions.

1. The contactor is closed by moving the pilot switch to the close position and is maintained through a control resistance which is mounted as a part of the remote-control circuit breaker.
2. The contacts are opened by moving the pilot switch to the open position.
3. The thermal trip unit contacts reclose automatically after tripping on overload, and operation to the close position re-establishes circuit to the load.
4. The motor can be forced against overload by holding the two-way momentary contact switch in close position.
5. The remote-control magnetic indicator is operated through the single control wire to show the position of the contactor.

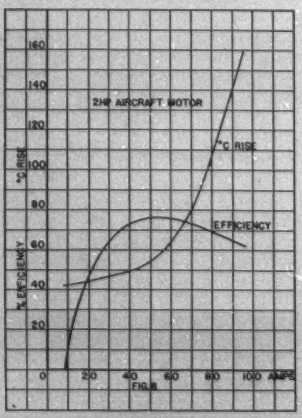

Figure 8

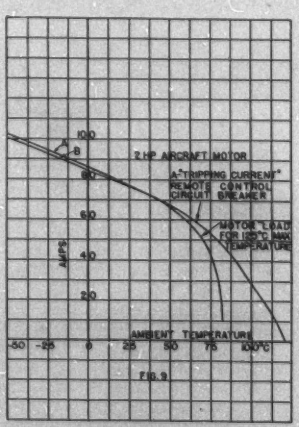

Figure 9

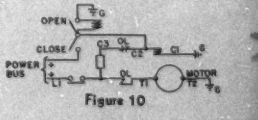

Figure 10

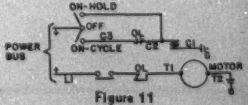

Figure 11

Relay Protection of Tapped Transmission Lines

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Synopsis: The war, with its attendant shortage of critical materials, has led to a considerable increase in the number of tapped lines. This paper deals with the method of protecting circuits of this kind under the three headings:

1. Pilot-wire protection, a-c and d-c schemes.
2. Carrier-current protection.
3. Other protective schemes.

Directional overcurrent or network.
Distance type.

Three-terminal lines are classified into three types with regard to other system connections between the terminals connected by the line in question. These are further classified as to power sources to aid in analyzing limiting conditions for relay applications.

Typical operating characteristics of a-c pilot-wire equipment for three-terminal lines are shown.

In general in dealing with pilot-wire, carrier, and other types of protection, those problems peculiar to application on three-terminal lines are analyzed and methods given for solving some of the more troublesome problems.

Introduction

THE interconnection of several power supply and load points by a single tapped transmission line rather than by a number of two-terminal lines has always presented first cost advantages at some expense in reliability and flexibility. However, the relay protection of such lines has been somewhat of a nightmare to protection engineers. Increased operating times for complete clearing of faults, and even some loss of selectivity have had to be tolerated in many instances. It has been said that there are no good three-terminal lines; some are simply worse than others. While inaccurate, this thought does express the general sentiment of protection engineers toward such layouts.

Nevertheless, the war, with its attendant shortage of critical materials, and manpower for construction, has led to a considerable increase in the number of tapped lines and placed increased load requirements on others already in service. Many war plants, because of their locations and high power requirements have been provided with supply with a minimum use of critical materials by tapping the nearest high-voltage line or lines. The circuit breakers usually have been located on the low-voltage side of the transformer.

The present paper deals with the methods of protection for such lines under the headings of:

1. Directional overcurrent protection.
2. Impedance or distance-type protection.
3. Pilot-wire and carrier-pilot protection

It is hoped that by summarizing the existing schemes and presenting data on certain new schemes, particularly on pilot-wire protection, that some help can be given in the solution of this currently important problem. It is also hoped that this paper will elicit discussion which will bring to light other schemes which various protection engineers have devised to solve the problems here discussed. Such discussions will be of particular benefit to the industry at the present time.

Typical Tapped Lines

Tapped lines appear in all the categories of main transmission, subtransmission, and distribution. Two hydrogenerating stations may be connected together and to a load and steam generation area over a high-voltage three-terminal line of the main transmission class. The substations of an a-c electrified railway[2] are fed from dual 132-kv lines with as many as ten substation transformers tapped from each line. The trolley system constitutes a 12-kv network. In the subtransmission class the four-kv network[1] ("high-voltage network") is a typical example of multi-tapped lines, the transformers which feed the network being tapped from lines such as 13.8 kv. Industrial plants will be found tapped at intermediate points of lines of practically all voltage classes. In many cases these plants have generating facilities in order to provide process steam. Hence, they must be relayed for line faults. Numerous other examples could, of course, be cited.

Classification of Three-Terminal Lines

The simplest three-terminal line is the straight radial arrangement with one

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6. The contactor will maintain its last operating position, should the control wire be broken or shot away.

A second control scheme, Figure 11, provides operation of the remote-control contactor by means of a three-position pilot switch. The contactor can be held closed against motor overload if the pilot switch is in the "on-hold" position. The overload trip unit contacts reclose automatically, and, if the pilot switch be in the "on-cycle" position, the motor will restart automatically, after tripping on overload. If the control wire is shot away or broken, the contactor will open or remain open as the case may be.

Conclusions

Military aircraft have extensive electrical systems. Circuit breakers are an essential part of such an electrical system. Their use insures that as much of this system as possible will remain available when the aircraft is subjected to enemy fire. These circuit breakers can combine switch and contactor functions with that of circuit protection, thereby reducing weight.

Military aircraft service often requires the immediate and maximum operation of motors so that motor overload protection cannot be provided. For those applications, where motor-overload protection is desired, circuit-breaker characteristics must be properly related to motor characteristics. Some such applications are of very intermittent duty and stalled motor conditions is the principle consideration for motor protection. Both manual and remote-control circuit breakers can be of the nontrip-free type to permit the operator to "force" the motor or other circuit devices beyond conditions which cause tripping.

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1. Application of Electric Power in Aircraft, T. B. Holliday. Electrical Engineering, volume 60, May 1941, pages 218–25.

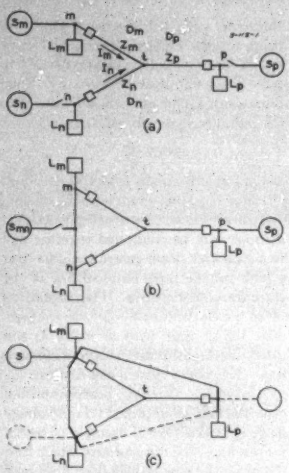


Figure 1. Classification of three-terminal lines

(a). No paralleling ties; one, two or three sources

(b). One paralleling tie; sources on connected terminal, or independent terminal, or both

(c). Paralleling ties between all terminals

S—Power source
L—Load
Z—Impedance

power source and two loads, fed solely over the line in question. As the number of sources is increased or other ties are included between the busses connected by the three-terminal line, additional relaying problems are introduced. Thus, from a relay-protection point of view, three-terminal lines may be classified into seven types as follows:

A. No paralleling ties, Figure 1a.

1. One power source.
2. Two power sources.
3. Three power sources.

B. Paralleling tie between two of the terminals, Figure 1b.

4. Power source on the connected terminals only.
5. Power source on the independent terminal only.
6. Power sources on both.

C. Paralleling ties between all three terminals, Figure 1c (with or without dotted portions).

7. The power source is effective at all terminals.

The classification as regards ground current is, in general, different from that for phase currents. For example, Figure 2 illustrates a three-terminal line with paralleling connections between all terminals for phase currents. However, ground faults on the tapped line cause no ground current in the other two lines. Thus, there are no paralleling connections for ground currents. Also, the two grounded transformers are the only sources of ground current for the tapped line. Thus, the relaying for ground faults is little, if any, different from a two-terminal line. This particular three-terminal line falls in the seventh classification for phase relaying but in the second class for ground relaying. High-voltage bussing throughout would throw it into the seventh classification for ground relaying also.

The Problems of Tapped Lines

The greater difficulty of relay coordination with tapped lines is due to a variety of problems that do not arise with the simpler two-terminal lines. For example, the impedance from one terminal to the two others may be different, introducing a problem in setting distance-type relays. Also, an impedance measurement at one terminal for fault near a

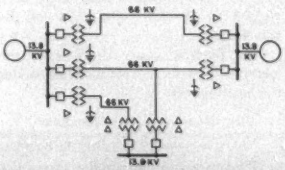


Figure 2. System showing three-terminal line with parallel ties for phase currents and only two sources with no parallel lines for ground currents

second is affected by current entering at the tap point from the third terminal, or by load current flowing to the third terminal. These two problems may occur on any of the seven classifications of three-terminal lines.

In addition, on the latter four classes, which involve paralleling ties, it is possible for fault power to flow out of one terminal for a fault on the line near another terminal. This frequently prevents the use of a straight blocking pilot scheme on lines of this class.

These problems and their solutions are dealt with in the subsequent paragraphs. Quite satisfactory solutions are possible by the use of pilot-wire[3] and carrier-pilot[4] relaying where these are feasible. Frequently the directional overcurrent or distance schemes depend for good operation on the strict maintenance of a normal system setup, or else sacrifice speed to use settings that will co-ordinate under adverse system conditions. The high-voltage network is an exception as will be explained.

Directional Overcurrent Protection

Three-terminal lines in radial circuits can be protected with standard overcurrent time-delay relays, as indicated in Figure 3. When additional sources of power are connected to the circuits, directional elements must be added to the relays. This circuit is indicated by the dotted construction on Figure 3. As the amount of power that must be transmitted over a given circuit is increased, the problem of maintaining system stability during faults becomes more critical and may impose limitations on the amount of time that is allowable for clearing faults. This usually eliminates the use of timed overcurrent relays, except in special cases where instantaneous overcurrent elements will provide the required speed of operation.

The high-voltage network[1] is an ideal example of a multiterminal-line arrangement that can be satisfactorily relayed. Each of the many taps is tripped by power reversal to the supply line, the system being so arranged that this can occur only during a fault on the supply line. This requires that all lines feeding a given network emanate from the same bus so that for normal load conditions the supply-line voltages are nearly equal and little or no reverse power flows through any transformer bank.

Many modifications of this basic scheme have been used in which some power reversal can take place when tripping is not desired. If such a reversed flow is due to a fault beyond the next breaker, time is introduced[1] for selection. If it is due to load currents, fault detectors have been successfully used, and, if the reversal can be due to either faults or loads,[2] fault detectors have been used to prevent operation on load currents and timing to provide selectivity for proper fault operation.

Usually such systems are arranged for

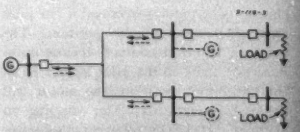


Figure 3. Overcurrent protection of three-terminal line

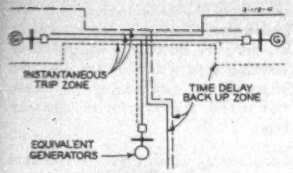


Figure 4. Impedance protection of three-terminal line

only one or two sources of ground current, the taps being tripped by residual voltage.

On long taps with overcurrent protection considerable improvement in selectivity can be secured through the use of angle discrimination. On such lines fault current occurs at a phase angle which could not occur for large load currents or swings.

Industrial Interconnection

When a line is tapped to an industrial plant having generation, it is common practice to segregate essential loads for operation from the plant generator and dump others in event of a line outage. If the same line is tapped for other plants, the problem arises of separating the plant under consideration from the line under conditions hazardous to its operation. One scheme in successful use on many industrial interconnections consists of separation based on any of three indications, provided power flow has reversed and is toward the power company. The three indications are: underfrequency, undervoltage, or generator overload. Any of these occurrences, provided power flow is away from the plant, is taken as sufficient cause for separating and at the same time dumping nonessential loads so that the remaining plant load may be brought within the capacity of the plant generation.

The relays normally employed are:

Induction-type overcurrent for generator overload.

Induction-type underfrequency relay.

Induction-type undervoltage relay.

High-speed-type three-phase directional relay.

The overload relay is directional controlled so that it will not start timing unless direction has reversed.

Directional relays are also used, without the voltage, frequency, or current fault detectors, for this purpose.

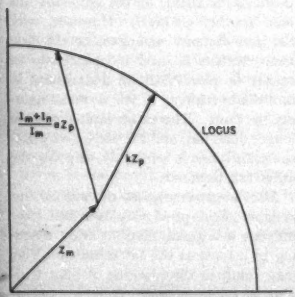


Figure 5. Graphical solution for balance point

$$Z_m+\frac{I_m+I_n}{I_m}aZ_p=Z_m+kZ_p$$

Given Z_m, Z_p, I_m, I_n (vectors) and either a or k (scalars) the other can be found by drawing the circular locus of impedance viewed by the relay

Refer to Figure 1a for nomenclature

Relay at m. Normal balance point is at Z_m+kZ_p from m

Balance point with mutual effect is at Z_m+aZ_p from m

Impedance or Distance-Type Protection

The general principle of application of distance relays to a three-terminal line is illustrated in Figure 4. As indicated, the instantaneous elements are set to include a zone that has a radius of approximately 90 per cent of the impedance to the nearest station. Faults beyond this zone will be tripped instantaneously by the near relay and, after a time-delay period has expired, at the remote terminals. However, certain problems arise which are not present in the application to two-terminal lines.

Unequal Impedances to Remote Terminals

Even in the simplest case of one power source and no paralleling ties, the three-terminal line presents a problem not present with two-terminal line protection. For example, with a source at m only, in Figure 1a, it is desirable to set the first zone element of an impedance relay at m for a large part of the line impedance to the next station. If p is much further away than n, the first zone instantaneous element can be set to trip only to 90 per cent of the distance to n. This leaves a considerable section of the line to p without instantaneous protection at m.

Also, the second zone impedance element at m must be set to trip beyond p in order to be sure of tripping end zone faults up to p. However, with this setting it may reach so far beyond n as to encompass another complete line section, whereas for proper co-ordination it should cut off somewhere in the first zone protective region of that next line section.

A similar problem exists with the third zone element which is set where possible to back up completely the subsequent line section.

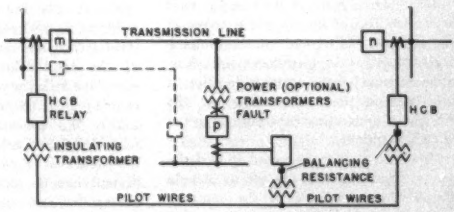


Figure 6. Typical three-terminal power circuit protected by three *HCB* relays

These problems occur also in the other cases where more sources and paralleling ties are present. It is evident that considerable advantage can be secured from a pilot channel to prevent the high-speed impedance elements from overreaching either of the other terminals, as will be described subsequently.

Mutual Impedance Effect

While the impedance relay operates on the ratio of current to voltage it is convenient to hold one quantity fixed and visualize the operation as the other quantity varies. Suppose a constant fault current is considered through the relay at m and the fault is gradually moved from the relay toward p. At first there is no voltage restraint, and the relay operates. As the fault is moved further away, the voltage restraint on the relay increases directly with the distance or impedance, until a so-called "balance point" is reached beyond which the voltage restraint exceeds the current operating force. Suppose that with a single power source this normal balance point is at 90 per cent of the distance to p and takes in 80 per cent of the section from t to p.

If a second source is introduced at n and the fault is again moved from m toward p, the restraint again increases directly until t is passed. Then, if the source at n provides four times as much current at the first source, the restraint increases five times as fast for distances of fault beyond t, since the current producing the voltage drop is five times as great in this section. The balance point is therefore reached at 1/5th of 80 per cent or 16 per cent of the distance from t to p. Or, in general, if the normal balance point is at an impedance, Z_m+kZ_p, from the relay, with a source at m only, and no paralleling ties, the balance point moves to an impedance

$$Z_m+\frac{I_m}{I_m+I_n}kZ_p$$

from the relay when the source or paralleling tie is added.

This "backing-up" of the balance point of a relay caused by current entering at the tap point is termed "mutual-impedance effect." It introduces complications because of the variable location of the balance point depending on the amount of generating capacity connected at each terminal.

However, it may be noted that if the second zone elements are set to include double the impedance of the common branch, tripping will always be assured although it may be sequential. Any current distribution that more than doubles the common branch as viewed from one terminal m, will less than double it as viewed from the other terminal n. The terminal with the larger current will therefore trip, eliminating the mutual effect, whereupon the other terminal will trip.

Mutual Effect of Loads

Even with a single source and no paralleling ties, load currents will have some effect on the balance point of impedance relays, particularly when fault and load currents are of the same order of magnitude. In Figure 1a with a fault at p, current to the load L_n, causes mutual drop in the branch m. Since this load current flows through the relay but does not create proportional restraining voltage by flowing over the line clear to the fault, it causes an overreaching effect which must be considered particularly in the setting of a first zone element. In terms of a normal balance point at a distance, or impedance, Z_m+kZ_p, the addition of the load L_n moves the balance point to an impedance

$$Z_m+\frac{I_m}{I_m+I_n}kZ_p$$

from the relay. This expression is identical with that given previously which makes the fraction $I_m/(I_m+I_n)$ greater than one. Starting with a normal balance point at Z_m+80 per cent of Z_p, a load flowing to L_n and constituting 40 per cent of the total relay current I_m, would move the balance point to Z_m+133 per cent of Z_p. (Note: 1/1−0.4 x 0.8= 1.33.) To prevent overtripping, the normal balance point must be reduced. A balance at Z_m+aZ_p with the load present can be secured by making the normal balance point:

$$k=\frac{I_m+I_n}{I_m}a \qquad (1)$$

Then, if $a=0.8$, $k=1-0.4/1\times0.8=0.48$. A normal balance point at Z_m+48 per cent of Z_p will be moved to Z_m+80 per cent of Z_p when the 40 per cent load is present.

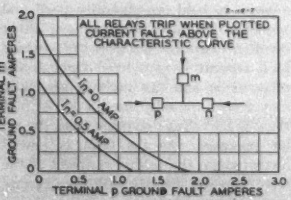


Figure 7. Typical tripping characteristic of *HCB* relays on a three-terminal line for internal ground faults

Relay set for maximum sensitivity. Pilot-wire resistance 200 ohms (each branch)

Negligible capacity between wires

Phase-Angle Effects

In the foregoing discussion the balance-point expression has been treated as algebraic which is, of course, strictly true only if the impedance phase angles are alike and the currents I_m and I_n either in phase or 180° out of phase. More generally the balance point occurs at Z_m+aZ_p where a can be determined by solving the equation

$$\left|Z_m+\frac{I_m+I_n}{I_m}aZ_p\right|=|Z_m+kZ_p| \qquad (2)$$

A graphical solution is shown in Figure 5.

Pilot-Wire and Carrier Pilot Protection

Pilot protection using either wire or carrier channels has proved to be quite an effective solution to the problems of relaying three-terminal lines. Two common types of pilot protection will be discussed here. They are known respectively as, first, the directional comparison or blocking type which is used with d-c pilot-wire or carrier-current channels, and second, the two-wire a-c pilot-wire type.

Directional Comparison or Blocking Type

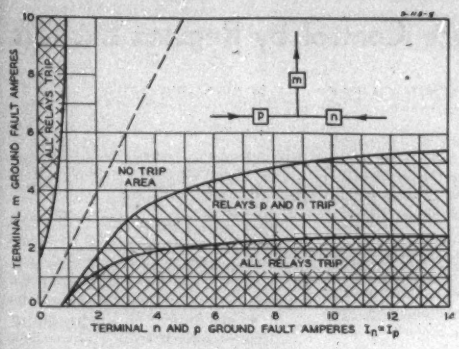
In the blocking scheme, directional fault-detector relays at each terminal trip for any faults in the tripping direction unless blocked by a signal from the far end indicating the fault to be beyond the far end of the line. This signal is usually initiated by a directional element which operates when power of fault magnitude flows out of the line at that terminal. Fault power flowing out at one terminal of a three-terminal line, to an external fault, will correctly block tripping at the other two terminals.

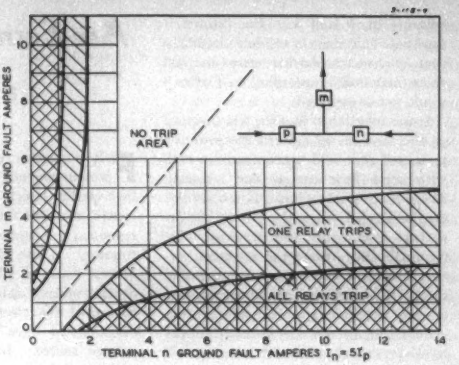
Such a blocking scheme is used with either wire or carrier pilot. One arrangement utilizes the step-type directional impedance relay as the fault-detecting element, and as the directional element for controlling the blocking signal, corresponding ground-current elements being used. The backup characteristics of step-distance relaying are obtained in this scheme without added impedance elements.

As previously explained, on systems with paralleling ties, as in Figure 1b or c, fault power may flow out at one terminal for a fault on the protected line near another terminal. However, with the step-distance arrangement the first zone element is used independently of carrier or pilot blocking and results in immediate tripping of the terminal nearest the fault. Thereafter fault power no longer flows out, and the carrier- or pilot-controlled relays promptly trip at the other two terminals.

Also, in extreme cases the mutual impedance effect, previously described, may prevent a tripping element from reaching to a fault at the far terminal. This may result in the blocking of pilot tripping at all terminals. However, operation of the first zone instantaneous element will in many cases open the breaker nearest the fault and remove the mutual effect. Pilot-controlled relays can then trip normally at the other terminals.

To summarize, distance-type pilot-wire or carrier protective systems can be applied to any type of three-terminal power circuit. Their operation may be slightly delayed when power flows out of one terminal of the faulted line or when mutual impedance effect prevents a





Figures 8 and 9. Typical operating characteristics of *HCB* relays on a three-terminal line

Instantaneous direction of ground-fault currents indicated by arrows, all currents in phase
Relay set for maximum sensitivity (0.5 ampere ground current per terminal)
Pilot-wire resistance 200 ohms (each branch)
Negligible capacitance between wires

tripping fault detector from reaching a fault near a far terminal.

Two Wire A-C Pilot-Wire Type

The *HCB* single-element a-c pilot-wire scheme,[8] developed in 1937, which has been widely used on short two-terminal lines, is also applicable to short three-terminal lines. In fact, such applications have been in successful operation in United States and Canada since 1939. The success with these lines and the greatly increased number of such applications at the present time has stimulated a considerable study of the limits of application of this type of equipment to determine how far it can be extended. Operating characteristics have been determined as the current distribution is varied, or the length of the tapped lines increased with corresponding increase in pilot-wire resistance and capacity. Some of the significant results of this analysis are presented here.

Principle of Operation

The *HCB* scheme of pilot-wire protection operates essentially as an extended bus-protection scheme, tripping all terminals whenever the totalized current to a fault within the protected zone exceeds a predetermined setting. It has variable ratio characteristics, produced by the restraining coils and a saturation device, that makes it relatively insensitive to ratio errors of current transformers on heavy through faults. The ratio characteristics are the same in percentage for any type of fault, phase, or ground; however, the relay has separate adjustments for phase and ground currents, so that the actual magnitude of ground current required to trip can be, and usually is, set considerably lower than the phase-current trip.

It is evident from the foregoing discussion that this scheme differs from the blocking types in that flow out at one terminal will not necessarily block tripping if the total net flow is "in" to a fault on the line. It is, therefore, ideal in principle, producing immediate tripping of all terminals for internal faults.

As the number of terminals is increased above two, and as the length of the pilot wire is increased, departures from the ideal of "extended bus protection" already described begin to be observed. For example, the minimum trip value increases with the number of terminals, and some variation is noted between the fault current required to trip different terminals, depending on the current distribution and the pilot-wire resistance and capacitance.

In the *HCB* pilot-wire scheme, restraint current is circulated through the pilot wires for through-fault or normal load conditions. With three terminals the three pilot wires are all brought to a common point and paralleled, their resistances being equalized up to this common point by means of balancing resistances as shown in Figure 6. For a through fault or load current flowing in at two terminals and out the third, restraining pilot-wire currents flow from the two terminals to the pilot-wire junction where they combine to form the correct pilot current to the third terminal. For faults within the protected zone the relay voltages act in opposition over the pilot wire, reducing the restraining currents and building up voltages which pass large currents through the shunt operating coils.

The operating characteristics of the *HCB* pilot-wire-relay scheme are illustrated by the charts of Figures 7, 8, and 9. If each relay is given a ground-current setting of 0.5 ampere, all relays trip whenever the total current to a fault in the protected zone totals approximately 1.5 amperes, or 0.5 ampere per terminal. The minor variations from this approximation are shown for moderate pilot-wire lengths in Figure 7. With equal distribution 0.5 ampere per terminal trips, whereas 1.9 amperes in terminal *p* alone is required to trip all three relays, the difference being due to the greater restraint current under the latter condition. This difference is usually of small significance.

The characteristic curves are given only for ground current, but it should be understood that the same curves apply for phase currents if the current scales are multiplied by a constant, that is, by the ratio of phase setting to ground setting given the particular relays.

The curves of Figures 8 and 9 are used first of all to show the amount of current-transformer inaccuracy that would be required to cause misoperation on a through fault. All current entering *p* and *n* must leave at *m* for a through fault. The currents *p* and *n* are considered equal and plotted as abscissa in Figure 8, while the current out at *n* is plotted as the ordinate. The curves separate trip from nontrip areas. Thus, two amperes in each of *n* and *p* (abscissa 2), and four amperes out at *m*, falls on the dashed line well within the no-trip area. In fact even should the ratio error of the current transformers at *m* be so great that only two amperes was delivered, the relay would still not quite trip. However, dropping to 1.5 amperes would cause undesired

tripping at p and n. The burden is moderate (1.6 ohms in residual circuit) so that current-transformer errors beyond those permissible according to Figure 8 would not be expected.

It was mentioned that the relay tripped on the basis of net current flow into the protected zone and hence operated even with some flow out at one terminal. There is obviously a limit to how far this can be carried, since the greater the departure from equal feed in at all three terminals the greater the restraint current flowing and the higher the operating value. With sufficiently high current out at one terminal, tripping will be prevented. Figure 8 is also intended for determining whether correct tripping will be obtained during an internal fault with maximum flow out at one terminal. It shows for example that if two amperes (secondary) flow in at each of p and n terminals, as much as 1.0 ampere leaving at m will not block tripping.

Curves similar to Figure 8 have been prepared for other than equal values of currents at p and n. Figure 9 shows the corresponding characteristic with the current at n equal to five times that at p.

It has been found from experience with a number of applications that the flow out is not sufficient to block desired tripping, as determined from data such as Figures 8 and 9. It can be concluded, therefore, that in practical cases, the *HCB* relay as used on three-terminal lines provides instantaneous tripping for all internal faults on three-terminal lines. Also it provides adequate margin to prevent operation on through faults even with quite large current-transformer inaccuracies. As mentioned, a number of installations have proved this to be a reliable means of obtaining high-speed (one cycle) relay protection on three-terminal lines. Standard equipment is used so that existing circuits frequently can be expanded simply by adding a third relay.

The pilot wires used should preferably be enclosed in cable sheaths, protected from lightning, induction, and differences in station ground potentials so as to maintain a continuous circuit at all times.[5,6] On three-terminal lines the shunt capacity between pilot wires should not exceed 0.5 microfarad per terminal for 500-ohm circuits. Continuous d-c supervision can be supplied with the relay to ring an alarm whenever any branch of the circuit is opened or faulted.

Conclusions

The co-ordination of directional overcurrent and distance-type relays is more difficult in three-terminal lines because of two principal problems.

1. Unequal impedances to remote terminals.
2. Mutual impedance effects from fault and load currents entering or leaving at the tap.

Blocking-type pilot schemes assist in solving these problems, but on three-terminal lines with paralleling ties undesired blocking may be produced by:

3. Power flow out at one terminal to a fault within the protected zone near another terminal.

The first zone element of step-distance-type pilot schemes solves this problem by operation independent of the carrier-current or pilot-wire blocking, but at the expense of a slight time delay.

The *HCB* two-wire a-c pilot-wire scheme circumvents all of these problems and provides uniform high-speed protection even in the more difficult cases of three-terminal line protection. Typical operating characteristics for three-terminal line operation are presented in the paper.

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Arc-Furnace Control by Regulex Exciters

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FOR a number of years prior to the present urgency for the production of high-quality steel, the development in control methods for electric-arc furnaces remained substantially stationary in this country. These devices were in the general form of vibrating regulators or contact-making ammeters which rapidly connected the electrode motors to and disconnected them from a constant d-c voltage source. In Europe, meanwhile, various methods employing Ward-Leonard or hydraulic control means were developed, some of which were reported to result in smoother operation under the highly fluctuating transient conditions of the arc.

Some six months prior to Pearl Harbor, study indicated that with stepless regulating or control means available in this country improved results might be effected. Such means consists of a rotating regulator in the form of a Regulex exciter. The first of this type control, here discussed, has now been in operation long enough for a definite judgment of operating results.

Qualities Required in a Regulator

1. Actuation from a measure of arc or heating energy.
2. Correction increasing in value as deviation from normal increases and decreasing to zero as deviation decreases to zero.
3. Quick response.
4. Stable antihunt means to prevent overshooting.

These requirements, of course, need to be met in any successful closed control system for governing or regulating. However, in the arc furnace the regulating problem is unusual because of the high degree of instability of the electric current and power in the arc.

By referring to A and A^1, Figure 7, film 2, it will be seen that fluctuations occur about every six cycles[1] near the beginning of a melt in a steel furnace. This is due in part to rapidity of changes in ionization, varying degree of rectification, and so forth. Obviously, it would be impractical to move an electrode system weighing perhaps a ton, in a six-ton furnace, fast enough to correct for these variations by control of arc length. Cur-

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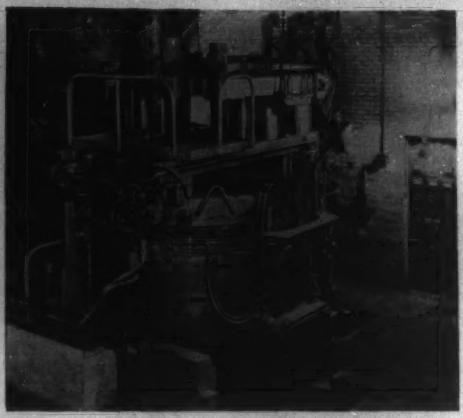

Figure 1. Six-ton top-charge arc furnace with operator's panel at right

rent is limited in such transients to a safe maximum value by transformer and lead reactance and where necessary an external reactance, as $X2$ in the equivalent circuit of Figure 3. But, under the same conditions, the variations in average values, from maximum to minimum as from A to B, Figure 7, film 2, occurs every one to two seconds. This is due in part to metal melting away, electrode melting, and so forth, which changes the arc length.

Thus a good regulating system must hold the average value to minimum variation. The Regulex exciter was selected for these requirements.

Rotating Regulators

Amplification

In a d-c generator rotating at constant speed, such as Figure 2A, the output power is controlled by the excitation winding CF. The machine is recognized as a power amplifier, and the control power in winding CF is a small percentage of the power output. This percentage

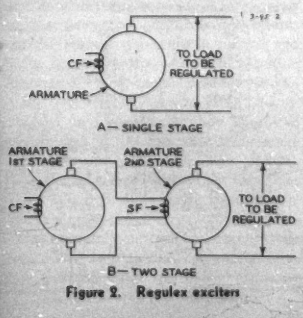

Figure 2. Regulex exciters

is two per cent to five per cent in a machine of standard commercial design giving an amplification factor of 50 to 20, respectively. This ratio is dependent on frame size and design, and in general the larger the frame size the greater the amplification factor for a given output voltage because the larger the frame the more flux per watt excitation is set up. Furthermore, by connecting two such machines in tandem as in Figure 2B the ratio of power output to control power is the product of the amplification factors of the individual machines. Therefore, with a given control power available, in the form of a measure of the quantity to be controlled, a wide variety of amplification factors are available to the engineer to obtain the necessary power output. The power output then is used to react on the quantity to be controlled whenever it varies from normal.

For example, in Figure 3, the control power available is current-transformer five-ampere metering and arc potential. Field 4 is designed for current-transformer metering current, and field 5 is designed for corresponding volt-ampere and ampere-turn capacity. The Regulex exciter 3 is the first stage of the amplifier and is of sufficient size to excite the electrode generator 2, which is the second stage. The second stage then is made of suitable capacity to drive electrode motor 1. This motor acts to change arc length when arc current and voltage vary from normal. Obviously for small electrode motors only one generator need be used.

Stability

The next most important consideration is stability of the system to prevent overtravel and "hunting." In the Regulex arc-furnace control, the actuating medium in the system is the resultant excitation of two opposed fields, 4 and 5, Figure 3, in the Regulex exciter. The control power is the sum of the excitation watts of these two fields. These fields are equal in ampere turns at normal value of arc watts or heating energy (the aforementioned quality 1 required in a regulator). No actuating flux being present, under this condition, no voltage is applied to the electrode motor.

Curve B, Figure 4, gives a typical volt-ampere arc characteristic. The change in voltage is not linear with change in current but is sufficiently large to satisfy quality 2. For small deviations from normal the actuating flux is essentially proportional to the deviation of arc watts from normal and the resultant power output to produce correction is essentially proportional to this deviation. This produces an inherently stable system where mechanical and electrical inertias can be neglected, thus signifying quality 4. Where these factors are appreciable, an anticipation of "cutoff" of the actuating flux proportional to such inertias is required. The amplification together with design for low inductance in all circuits satisfies quality 3 as will be later shown.

Sensitivity

The sensitivity of the system depends on amplification ratio, friction in the electrode system, and hysteresis in the electrical machines. As will be seen from the volt-ampere characteristic, curve B, Figure 4, at very low currents the change in arc volts is greater per unit change in current than at higher current values. For this reason good sensitivity is maintained inherently down to very low currents. The system is quite stable at 10 to 15 per cent current which is necessary to prepare furnaces for operation after relining (burning bottom).

Arc-Furnace Control

An arc-furnace installation is subject to greater fluctuation in power and surges[2] than other installations requiring control because of:

(*a*). More frequent switching.

(*b*). Wide range in primary transformer taps to provide necessary secondary voltage.

(*c*). Large reactance to limit maximum current.

(*d*). Varying amount of d-c component in the arc.

(*e*). Rapidly fluctuating state of ionization in the arc.

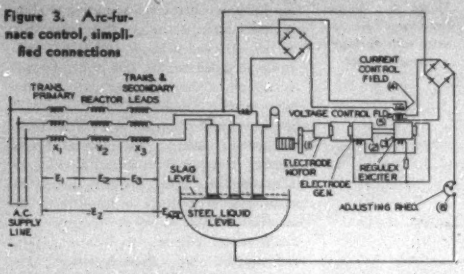

Figure 3. Arc-furnace control, simplified connections

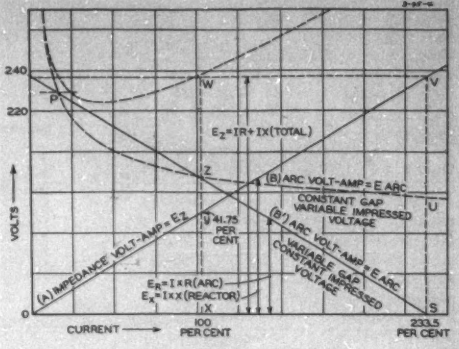

Figure 4 (right). Typical arc-circuit characteristics

The last item *e* has greatest effect from the control standpoint.

The complete system, here under consideration, consists for each electrode, of a Regulex exciter controlling a generator of suitable size with its armature connected electrically directly to the armature of an electrode motor which raises and lowers the electrode. In addition, there are the necessary control switches, meters, indicating lights, and so forth. This equipment is duplicated for each electrode. For a three-phase furnace three Regulex exciters, three genrators, and an a-c driving motor form a small seven-machine motor generator set. The complete connections are shown in Figure 5. The motor generator set, as shown by the connections, may be supplied from the furnace bus, thus making the entire installation self-contained, and not dependent on a separate d-c power source. Figure 6 shows the control equipment from the rear of the operator's panel. The panel at the left mounts, plate-type rectifiers, control resistors, and so forth. On small electrode motors, generally under one horsepower, the Regulex exciter armatures are connected directly to the electrode motors, thus resulting in a small four-machine control unit.

As shown in Figure 5, current settings in each phase are made by rheostats *R1*, *R2*, and *R3* in the arc-potential circuit. By changing, for example, the excitation of *VF-A*, the phase current is automatically changed, since the differential flux between *VF-A* and opposed current field *CF-A* produces voltage to run the electrode in the proper direction (raise) until the fields are equalized.

Four voltage positions normally are provided on the transformer tap changer. On the highest voltage all of resistance *R1A*, *R2A*, and *R3A* in the potential circuit are connected in the circuit. When the circuit is changed to the next lower

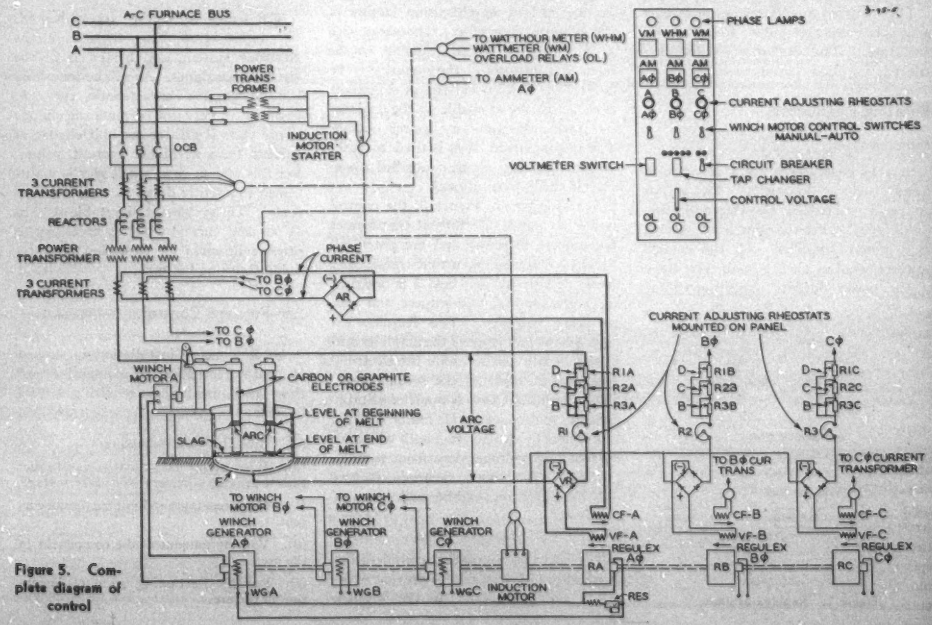

Figure 5. Complete diagram of control

voltage, contact *B* automatically short-circuits resistor *R3A* so that on the new voltage the current setting is not changed. Contacts of *B* also perform the same function on the other phases, and for other voltages contacts *C* and *D* act in like manner.

Operation of the Control in Service

A good image of the net operation of the control can be obtained from examination of oscillograms taken with a furnace in operation. The films of Figures 7 and 8 were taken on a steel furnace of six tons nominal charge capacity. Arc energy is supplied through a furnace transformer from a 22,000-volt three-phase 60-cycle line. The analysis of the melt was

Carbon	0.35
Manganese	0.14
Silicon	0.43
Phosphorus	0.035
Sulphur	0.037

In all films, which were taken on a single phase, the oscillogram traces starting at the top of the film and progressing downward measured the following:

1. Arc volts.
2. Electrode (or winch) motor, armature volts.
3. Arc amperes.
4. Voltage-control-field amperes (rectified).
5. Current-control-field amperes (rectified).
6. Electrode (or winch) motor armature amperes.

All values are rms except rectified Regulex-control-field currents which are peak values.

In film 2, Figure 7, taken 15 minutes after the start of the melt, just prior to sudden current increase, at *A*, the electrode motor was operating at 75 volts and lowering the electrode at 10.85 inches per minute. With the sudden current increase the motor was reduced to zero speed in 26 cycles. However, it was not decelerated at a constant rate, as can be seen from the motor armature current. As the average difference in current and volts decreased, the rate of deceleration decreased. The motor reached practically zero speed 26 cycles later and remained so for approximately 35 cycles up to point *C*. At this point the average arc energy had dropped below normal, and the motor accelerated for 35 cycles until it had 90 volts across its armature. At this point the average arc energy became essentially normal, and the electrode speed remained at 14.35 inches per minute lowering, and the motor armature current ran to approximately zero.

As will be shown later, between points *E* and *B*, mutual inductance between the two opposed control fields prevents response to the peak values of only a cycle or so duration. However, following point *B*, the current rose sharply from about 5,000 amperes to 18,400 amperes, and the motor was decelerated to zero speed in about 10 to 11 cycles and reversed. Here a high "pump-back" current is regenerated in the electrode-motor armature.

Consider the action at point *F*. Prior to reaching this point because of too low arc energy, the electrode motor had been accelerated to lower the electrode until 106 volts were across its armature. The increase in current at this point, with little decrease in voltage starts decelerating the motor. However, as previously mentioned, at this point in the heat, metal is running away from the electrode as it melts, thus tending to increase arc length inherently and to reduce current. At the same time the electrode is lowering. Consequently, the rate of lowering the electrode decreases only until the average *actuating measure* of arc watts is reduced to normal which is not necessarily *zero speed of the electrode*. In examining the electrode-motor armature volts for the entire length of film 2, the electrode is raised four times, with only slight movement each time. The total area under all of these raising voltage swings below zero, compared to the total area under the lowering loops above zero, shows that the electrode is lowered through the scrap at such a rate as to maintain as near constant average heating value as the response of the system to the extreme fluctuations will allow.

Film 4, the lower one in Figure 7, was taken 65 minutes after the start of the melt of film 2. Much of the steel has been melted down, and conditions are steadier. The film speed is such as to show the general wave shape of current and voltage. At point *H* on the film, it will be noted that current jumped from 5,240 amperes to 13,100 amperes on successive peaks. However, the rectified-voltage control-current peak increased on this half cycle, because of mutual inductance, even though the voltage was sharply reduced. But the average of the next four half cycles is reduced from the previous four half cycles with a net small response from the Regulex unit. This characteristic is of particular value in refining at the end of the melt to prevent false movement when the metal is "boiling." When a bubble rises against the electrode and disappears within a cycle or two, after bursting, no movement of electrode results.

Film 8 at top of Figure 8, was taken one hour and 55 minutes after the start of the heat of films 2 and 4 and consequently during the refining period. Iron ore and

Figure 6. Rear view of operator's panel showing auxiliary panel and Regulex exciter motor generator set

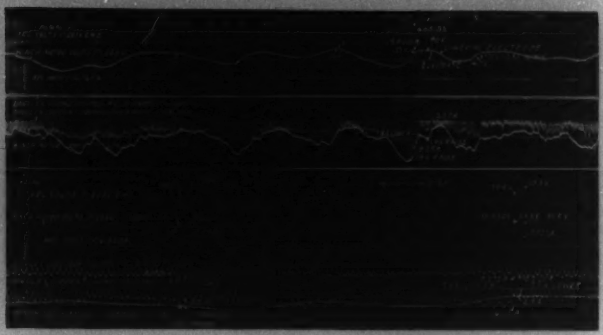

Figure 7 (above). Film 2 and film 4

Film 2 taken 15 minutes after start of melt. Transformer on *A* tap, 205 volts phase to phase, 14.3 per cent impedance. Time 10:15 p.m. Film speed approximately 1¼ inches per second. Heat 21071. Saturday, November 21, 1942. Charge 2,000 pounds turnings, 9,600 pounds gates, 6,400 pounds plates (nine tons total)

Film 4, same heat, taken 65 minutes after start of melt. Time 11:05 p.m. Transformer on *A* tap, film speed approximately 23 inches per minute

Figure 8 (below). Film 8 and film 11

Film 8, same heat taken one hour 55 minutes after start of melt, 11:55 p.m. Transformer tap *C*, 127 volts phase to phase, 9.4 per cent reactance. Film speed approximately 1¼ inches per minute

Film 11, heat 21075. Sunday, November 22, time 3:10 p.m. (furnace shut down approximately 7:00 a.m. Sunday morning, restarted 3:10 p.m.). Start of melt. Transformer tap *A*, 205 volts phase to phase, 14.3 per cent reactance. Film speed approximately 1¼ inches per second. Same scrap and analysis as on film 2

other elements had been added shortly before and created violent boiling sufficient to necessitate a cutoff of power to prevent boiling over. The film shows regulation just after reapplication of power after boiling had subsided somewhat.

Film 11 was taken at the beginning of a heat next day. The control was purposely set so that when it was placed under automatic regulation to lower electrodes onto loose scrap, one electrode would strike the scrap in advance of the one being recorded. At point *I* to the right of the film when the electrode touched the scrap placing full-phase voltage between electrodes, the electrode motor speed was increased correspondingly. At points, *J*, *K*, *L* when the electrode first came in contact with the loose scrap, the arc was "struck" and broken some eight times before being firmly established. Thereafter, it was not lost for the duration of the heat except for interruptions by the operator for tap changing, and so forth.

It is to be noted particularly how electrode motor speed was reduced as the arc was established, until at the extreme left of the film it has reached a speed comparable to the lowering speeds of film 2. Also of interest is the low magnitude of arc current when the arc is initially established.

Power Consumption

Power consumption is, of course, dependent on many variables including type of material melted, method of feeding material into the furnace, use made of the furnace such as melting or refining, and so forth, so that kilowatt hours per ton vary from one installation to another. The control is only one element in any comparison. However, on furnaces of the same type and rating, in the same plant, evidence of more uniform resultant heating has been reflected in more heats per day as compared to older methods of control. Figures are not given because the results are unexpectedly favorable and need verification in other installations to be put into service, where comparisons with previous equipment can be made.

Effects on Power System

Previous papers[3] before the Institute have shown that maximum disturbance on the power system occurs when the arc is made or broken. From film 11, Figure 8, and the other films, it may be seen that once the arc has been established firmly, at the beginning of the melt, it is not broken again before the end of the melt, except for interruptions for voltage change, and so forth.

Also, it has been found that a lesser reactance may be used than with older methods, thus improving power factor to some extent with less net voltage disturbance. Comparative data are not available on this general comment.

Conclusions

1. A stepless direct acting regulator is readily adaptable to highly fluctuating electrical quantities.

2. Application of such control to arc furnace has improved efficiency and reduced power consumption and maintenance.

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Aircraft Electric Power-Supply System

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Synopsis: An ever increasing demand for electric power in aircraft has been felt for some time. The necessity of using an electric storage battery started the practice of accompanying it with a d-c generator, first of low current and voltage capacity, later of 50-ampere 12-volt rating, and for the past few years of 200-ampere 24-volt output. In the largest four-engine aircraft, even four generators of maximum capacity do not furnish ample electric energy. Experiments have proved so far that generation of a-c power and application of lightweight transformers, together with its conversion to direct current by means of selenium rectifiers, is entirely a reliable and practical way of attaining large, trouble-free electric plant capacity in aircraft. The subsequent pages and illustrations portray the current progress made with lightweight power transformers and rectifiers in the a-c-d-c aircraft systems. They also represent at least a partial answer to the questions raised by Lieutenant Colonel Holliday[1] when he discussed problems of applications of electric power in aircraft two years ago.

THE development of a-c-d-c power systems for aircraft application started with a view of achieving two main objectives:

1. Augmenting the source of electric energy offered by conventional d-c generators.
2. Alleviating the difficulties of commutating machinery and voltage limitation under conditions of high-altitude operations.

Furthermore, having alternating current as a primary source of electric energy, some of the a-c powered equipment in the aircraft can readily be used with or without resorting to transformers, whereas d-c operated devices may be powered through rectifiers with or without transformers.

The first stage of early development was to duplicate the largest d-c generator of 200-ampere rating, operating the so-called 24-volt system, with the output voltage set at 28.5 volts in order to maintain the proper charging rate of the battery.[2] The weight, efficiency, and, to some extent, the bulk of the generator were to be at least duplicated or, if at all possible, were to be met more favorably with a combination of alternator and rectifier.

The paramount requirements of the aircraft power rectifier narrowed down to the following three:

1. High efficiency.
2. Minimum weight.
3. Satisfactory service.

An efficiency of 84 per cent appeared to be feasible and acceptable. A unit of six-kw rating, with suitable enclosure and connecting terminals, would receive favorable consideration if its weight could be in the neighborhood of 15 pounds. The larger-sized units are to be a multiple of this one. Satisfactory service could only be expected if the performance of the rectifier is:

1. Fairly uniform under extreme temperature, humidity, and altitude conditions.
2. Unaffected by vibration.
3. Capable of maintaining good operating characteristics for at least 500 hours if not longer and with a reasonably small amount of air-blast cooling.

The transformer, on the other hand, from the very start presented one important problem, that is, the attainment of the lightest possible weight. The air-blast cooling was set out to be a definite means of meeting this requirement. As it happened, however, the latest kind of material and the unique design produced very gratifying results.

The requirement, design, and performance factors of the alternator constitute an ample subject for their own discussion. It is sufficient to state here that even the early alternator, powering a 200-ampere 30-volt rectifier, was 26 pounds in weight and 90 per cent efficient. Several selenium rectifiers were designed, built, and tested under low and high temperatures, rarefied air, and excessive vibration conditions. Their performance was in every respect satisfactory and, therefore, promising.

In order to evaluate fully the soundness of higher power generations,[3] plans were drawn to build an aircraft electric system capable of delivering a d-c output of 800 amperes, 30 volts, under varying temperature and humidity conditions and with a reasonably small amount of air-blast cooling. Such a system, Figure 1, comprising alternator, transformer, and rectifier, was built and tested.

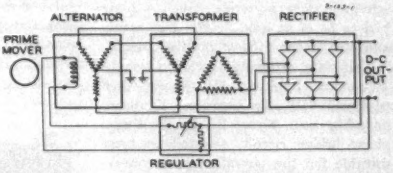

Figure 1. Block diagram of aircraft electric plant of 800-ampere 30-volt d-c rating

Rectifier

Even during early experiments with a 200-ampere rectifier, it became evident

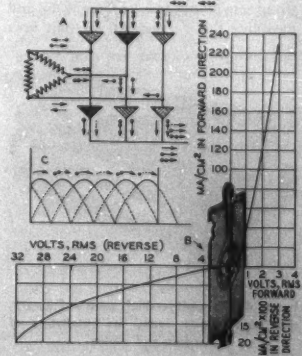

Figure 2 (right). High-voltage selenium rectifier plate

A. Diagram of three-phase bridge circuit and distribution of current in its six arms

B. Operating characteristic, forward and reverse voltages in rms values, and the currents in arithmetical values, as they function in three-phase bridge circuit. Cut shows four layers of rectifying element: back electrode, selenium layer, barrier layer, and front electrode

C. The net result of performance of the six arms of the bridge circuit during each cycle

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The author wishes to express thanks to the officers of the United States Army Air Forces, engineers of the Chrysler Corporation, and to the colleagues of his own organization for their co-operation in carrying on these experiments.

Figure 3. Aircraft rectifier, three-phase input, 200-ampere 30-volt d-c capacity

Top and side covers removed. Weight 15 pounds. Rectifying elements occupy less than 0.25 cubic foot and weigh 11 pounds

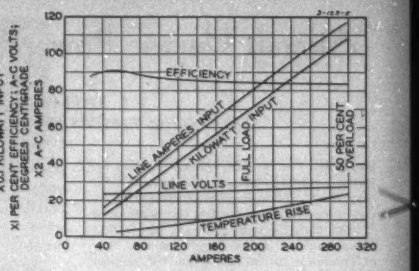

Figure 5. Operating characteristics of rectifier unit shown in Figures 3 and 4

Rated at 200 amperes, 30 volts, at ambient temperatures from minus 70 to plus 50 degrees centigrade. Unit is capable of withstanding 50 per cent current overload continuously for ten hours

that if selenium rectifiers were to play a role in 24-volt aircraft systems, the design and technique of the manufacture of selenium plates had to be modified at least to the extent of using a single selenium plate in series. Such a plate had to be of at least 28-volt rms rating and still of the lightest possible weight.

This plate, as finally developed, weighs $1^1/_4$ ounces bare and $1^3/_4$ ounces when equipped with the necessary hardware including fuse, Figure 2. In the three-phase bridge circuit, selected as most suitable for the aircraft power conversion, this selenium plate accounts for 12.5 amperes of the entire current output at 30 volts d-c with 350 cubic feet of air per minute. It is fitting here to once more reiterate the function of this type of rectifying element. The phenomenon of electric current rectification wholly takes place in the barrier layer which, in this particular plate, has been strengthened in the reverse direction but with the minimum adverse change in the forward direction. The static characteristic of a metal rectifier is determined by applying, first, d-c voltage in the forward direction (from zero to one, two, or three volts) and recording the d-c current per unit area (milliamperes per square centimeter); and second, by applying d-c voltage from zero to maximum plate voltage in the reverse direction and measuring the current leakage in milliamperes per unit area.

There is a total of six arms in the rectifier of the three-phase bridge circuit, but only two arms function during each one sixth of a cycle. The remaining four arms are blocking, Figure 2*A*. Since the total d-c output is greater than 12.5 amperes, several plates are placed in parallel. The rectifier of 200-ampere 30-volt rating has a total connection of 6–1–16, and the figure 16 designates the number of parallel plates in each arm of the bridge circuit. Physically all 96 plates are assembled into three stacks, interconnected with suitable bus structure and are housed in a lightweight case designed and built in accordance with usual aircraft practice, Figures 3 and 4.

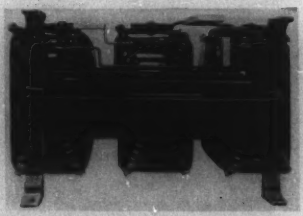

Figure 6. Aircraft transformer, air-cooled, 33.7-kva 400-cycle three-phase, 250-volt primary winding, 28-volt secondary winding

Weight 30 pounds. Front view. Over-all length ten inches

Figure 4. Aircraft rectifier, same as Figure 3, side covers open, ready for installation of conduits and cables

The upper section of Figure 2*B* illustrates the function of the selenium plate in the passing or forward direction. There is a certain amount of voltage drop per plate. This drop varies with the current density or the total output of the rectifier and constitutes forward losses. In a rectifier giving an output of 200 amperes, its value is in the neighborhood of 2.3 to 2.7 volts. This drop, however, changes with the time of service of the rectifier. Its increase during 500 hours of continuous operation may bring a net result of five per cent drop in the d-c output with the same a-c input to the rectifier. For some time, it had been expected that an idle condition of the rectifier would give a marked increase in this voltage drop. To date, however, observations have shown that this is not the case, although some momentary deforming of selenium plates may be expected after long idleness.

With the two arms of the bridge circuit passing the current in forward direction, the remaining four arms are blocking. An ideal rectifier would block reverse current completely. Actually, however, there is a certain amount of current leakage. Its value depends on the operating temperature to some extent but mainly on the length of service of the rectifier itself. The lower curve of Figure 2*B* illustrates a typical leakage current characteristic at an ambient temperature from 10 to 40 degrees centigrade. At both ends of this temperature range, the leakage current increases. Under all temperature conditions, however, the currrent leakage decreases with the life of the rectifier. The curve represents a typical reverse voltage-current density

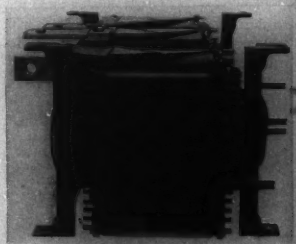

Figure 7. 33.7-kva three-phase air-cooled transformer, same as Figure 6

Side view. Over-all width seven inches

relation observed with two plates opposing each other. In the actual three-phase rectifier circuit, the reverse current is somewhat higher than that shown in Figure 2*B*, since the effects of all plates are integrated over the entire cycle. Computations and subsequent tests showed that the total current leakage of a 200-ampere rectifier is approximately 2.4 amperes at the start of service and is in the neighborhood of 1.6 amperes after 500 hours of continuous operation.

The necessary a-c input voltage to give the required direct current output voltage is computed by means of already established formulas.[4–6]

$$V_{ac} = 0.74 \times 30 + 2 \times 1 \times 2.7 = 27.6 \text{ volts}$$

The performance of this rectifier is illustrated in Figure 5.

Transformer

In the design of the transformer, full advantage was taken of improved materials and latest methods. Following the general aircraft practice of obtaining minimum weight and highest efficiency, high-permeability low-loss silicon steel was selected for the core structure.[7,8] Since the transformer was to operate under conditions of high magnetic induction, this type of steel, insulated with a silicate glass and processed under a rigidly controlled technique of heat treating and crystal orientation, was to give maximum amount of flux, some 40 per cent more than the best transformer steel, with a remarkably small external magnetizing force. Furthermore, this material permits not only lower total losses, including copper losses, but also their better balance, greater short-time overload capacity, lower impedance, and better voltage regulation. The latter measured 12 per cent and with the flux density of 16,150 lines per square centimeter and resulting core losses of 320 watts at 350 cycles per second, the efficiency of the 33.7-kva transformer was 95 per cent at full load. As the frequency increases, the core losses decrease. Even with the frequency 25 per cent higher, when the flux density was in the neighborhood of 12,800 lines per square centimeter, the core losses decreased almost 40 per cent. At these high frequencies, the machined butt joints also added to the high performance of the transformer.

Both windings were designed with a view to keeping copper losses to the minimum. This has been accomplished with the use of a rectangular wire for the primary windings and with the use of very thin and wide flat copper strips for the secondary windings. In this manner, the radiating area of the copper was increased markedly, and, since there is a certain amount of skin effect in the conductor under the conditions of high frequency and high current, this feature helped greatly in keeping copper losses down. With the current density of 6,600 amperes per square inch in the primary winding conductor and some eight per cent less in that of the secondary, the copper losses at 75 degrees centigrade were only 620 watts and 610 watts for primary and secondary windings, respectively.

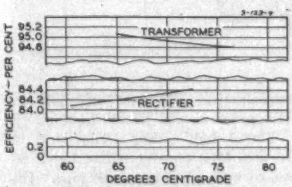

Figure 9. Characteristics illustrating the effect of temperature upon efficiencies of transformer and rectifier

All other material employed in this transformer was also selected with the sole objective of obtaining optimum performance. The winding, for instance, is separated from the core by means of heat-resistant glass cloth-base laminated plastic. The ventilating ducts in the winding are formed by means of sticks made from the glass cloth-base plastic. The frame itself is made of four corner supports welded from pieces of high-strength aluminum alloy. The supports are clamped to the core with a steel tape in such a manner that vibration stresses are taken by the supports rather than by the entire transformer structure. This type of frame construction contributed greatly in achieving lightness of weight, Figures 6 and 7.

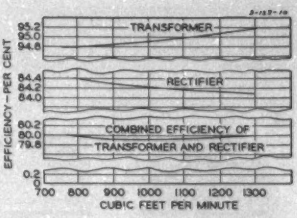

Figure 10. Transformer and rectifier efficiency characteristics as affected by the amount of cooling air

The secondary winding, carrying approximately 375 amperes, is spirally wound and has a-c resistance much lower than the conventional type of winding, The actual amount of 650 watts of copper losses in such a winding at 1,000 cycles per second frequency and 150 degrees Fahrenheit operating temperature would be some six times as great if the same winding were made of a square wire, of the identical cross-section area and arranged in a single layer. Furthermore, the copper-foil winding facilitates cooling, since the thin and wide strip has a surface area of almost six square inches per inch of conductor length, whereas, the square wire conductor has a surface of one square inch per each inch of conductor length.

Alternator

During the past year, several alternators were designed, built, and tested. Two voltage ratings (250 and 28 volts, line) were tried. The alternator used in Figure 1 experiment was of 35-kva 250-volt rating. Two more alternators became available. One is 16 kva to operate with the rectifier delivering 400-ampere 30-volt output; another of still lower kilovolt-ampere rating, Figure 11.

This aircraft alternator is rated at

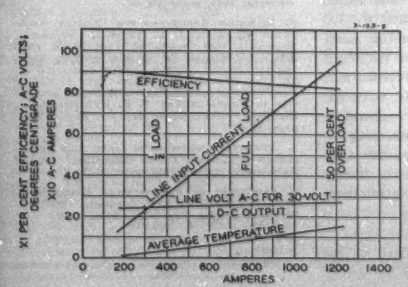

Figure 8. Performance characteristics of 800-ampere 30-volt rectifier used in Figure 1 system

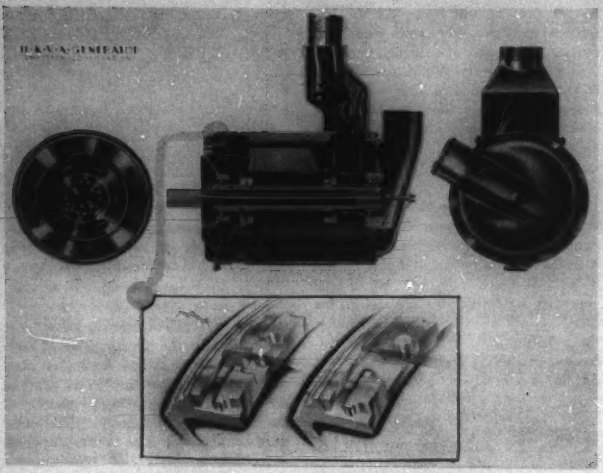

Figure 11. 11-kva three-phase air-cooled alternator, weight 33 pounds

Top, from left to right:
1. Engine pad view of the alternator
2. Section through alternator
3. Cooling cap and terminal block

Bottom, enlarged details of bayonet-type mounting flange. On left, alternator initially placed on flange. On right, alternator in locked position

11 kva, three phase, 30 volts, 211 amperes, 440 cycles and is capable of delivering 10.45 kw at 95 per cent power factor and at the minimum speed of 4,400 revolutions per minute. It was designed for a field current which could be handled by the 28-volt 200-ampere voltage regulator normally available; therefore, it does not represent the lightest possible design which could be achieved by a heavier field current (12 amperes) and a special regulator. Its approximate weight is 33 pounds.

The stator is delta-connected with two parallel circuits per phase. There are 72 semienclosed slots with two slots per pole per phase and full pitch winding. Rectangular wire is used in the stator winding to obtain maximum ratio of copper to slot area. Paper insulation is used since the alternator temperature rise is kept within class *A* insulation limits. The 12-pole rotor is skewed. Metallic slot wedges are used for the rotational speeds encountered. The field coil ends are strapped to metallic reinforcing rings.

Forced draft cooling is employed. A six-inch total pressure differential is required with a two-inch blast pipe. The internal air passages are so arranged that reverse flow of cooling air is caused, and thus more efficient use is made of the available air.[9]

800-Ampere 30-Volt Electric System

The first unit (Figure 1) with rectifier having operating characteristics shown in Figure 8 and supplying a total output of 24.6 kw, 0.6 kw of which was used by the field circuit of the alternator, has been tested under ordinary laboratory conditions and has given an over-all efficiency of 72 per cent. The efficiencies of the transformer and rectifier are affected by the amount of cooling air and, therefore, by the operating temperature of the respective units, Figures 9 and 10. The amount of cooling air was varied from 750 cubic feet per minute to 1,300 cubic feet per minute. Over this range of volume of cooling air, the combined efficiency of the transformer rectifier unit remained practically constant, since the efficiency of the transformer decreases and that of the rectifier increases with the temperature rise. It follows then that the minimum volume of air can be chosen to maintain both components within their safe temperature limits.

High-Altitude Operations

The high-altitude operations constitute unusual conditions of rarefied air and extreme low temperature. The 200-ampere rectifier unit without transformer has been tested in a stratosphere chamber under 45,000 feet altitude and minus 43 degrees centigrade temperature conditions.

The results could readily be analyzed in the light of the same characteristics shown in Figures 9 and 10. Referring to Figure 9, it can be seen that rectifier efficiency decreases steadily as the temperature goes down. At the same time, however, efficiency increases with the reduction of the cooling air as a result of the higher internal temperature of the rectifier. The net result is that both effects tend to balance each other and to maintain the efficiency of the rectifier at a point governed by percentage of loading.

Conclusion

It is gratifying to comment here that at present a large amount of work is being carried on by capable engineers and manufacturers connected with or serving the aviation industry. The results no doubt will bring about the availability of several flexible electric systems from which to choose one meeting particular requirements.[9]

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Formulas for Calculating Short-Circuit Forces Between Conductors of Structural Shape*

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THE mechanical forces acting on bus-bar supports during short circuit are determined both by the magnitudes of the mutual electromagnetic forces exerted among the bus conductors and by the elastic properties of the supporting structure: its motional resistance, natural frequencies, and physical nature and arrangement. Comprehensive mathematical studies,** substantiated by experimental data, of the individual and collective effects of these factors and general methods for calculating the magnitudes involved have been advanced by Schurig and Sayre,[1] Dahlgren,[2,3] and Pilcher.[4] In shorter articles based on the work of the first-named Schurig, Fricke and Sayre,[5] Tanberg,[6] Specht,[7] Edson,[8] and others[9] have presented certain charts, nonograms, and short cuts that facilitate the numerical labor incident to actual calculation.

Now though the circumstances of a particular problem may render certain of these methods more advantageous to use than the others, *all require calculation of the mutual electromagnetic forces exerted among the conductors of the bus.* Commonly the bus is comprised of a group of long linear parallel nonmagnetic cylindrical conductors. If so, calculation of the electromagnetic force acting on a specified conductor resolves into successive determination of the magnitudes and phase relationships of the currents in the conductors, of the mutual force exerted between the given conductor and each of the others, and of appropriate vector summation of these last.

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* As the formulas pertinent to conductors of full or annular circular cross section are well known, they are not treated in this paper.

** While the work of the first named is frequently cited in the American literature, that of the other two, seemingly, has attracted but little attention. Yet Pilcher's work is an extension of the theory delineated by Schurig and Sayre; while Dahlgren's, an extended study of the important phenomenon of mechanical resonance, complements both.

Calculation of the actual short-circuit currents requires use of symmetrical components. General procedures specifically adapted to short-circuit calculation of industrial-plant distribution systems, together with inclusive pertinent numerical data (electrical constants of standard types of conductor, of typical busses, and of the usual attached electrical apparatus), are encompassed in elaborate works by Hanna[10] and by Darling.[11,12] Illustratively, Schulze[13] has given a detailed numerical analysis of the short-circuit calculation of a typical plant distribution system. Other phases of the problem of calculation of the short-circuit currents have been discussed by Papst,[14] Schurig,[15] Leonard and Riker,[16] Gross,[17] Robinson,[18] Tripp,[19] and Kilian.[20,21]

However, between finding the short-circuit currents (for which step are available all the methods and data contained in the papers mentioned in the preceding paragraph) and summing the forces exerted on the specified conductor by the other conductors (which step for a d-c bus requires but simple arithmetic and for an a-c bus the only slightly less simple task of adding complex numbers) is the intermediate and important task of *finding these individual forces.* Theoretically, if the conductor currents and geometry are known, these forces can be calculated by use of fundamental electromagnetic theory. Practically, the mathematical analysis requisite to use of this theory is far from simple—if not actually intractable—and the bus designer turns, perforce, to the use of known formulas or, if these latter be lacking, to some type of approximation, the accuracy of which is more or less indeterminate.

Obviously, resort to such approximation, certainly inconsistent with good engineering practice, is most undesirable. Yet there is little choice to the contrary. For, though the mechanical and electrical advantages stemming from the use of linear conductors of structural shape are so marked that, at present, most busses for heavy-current duty are constructed of such conductor; and, though standard designs of single and polyphase busses utilize strap, rectangular, tubular, channel, angle, tee, and I-beam conductor, a recent exhaustive survey[22] of the literature reveals, seemingly, that explicit formulas for calculating the electromagnetic forces between two conductors of the shapes mentioned are virtually nonexistent. A paper by Dwight[23] contains formulas and curves for calculating the force between two identical conductors having parallel coplanar axes and parallel-sided rectangular cross sections. And papers by Higgins[24,25] contain formulas for calculating the force between two identical conductors having parallel coplanar axes and parallel-sided full or hollow rectangular cross sections. But, despite extended and increasing use, there have not been published explicit formulas for calculating the force between conductors (not necessarily identical) of parallel-sided full or hollow rectangular conductors arranged other than just described; or for any arrangement of conductors of angle, channel, tee, or *I*-beam shape; or for any arrangement of composite conductors constructed of combinations of two or more of these six shapes.

Such formulas are derived in this paper, it being assumed that the conductors are nonmagnetic, are of such length that end effects are negligible, are right cornered, and carry current distributed uniformly over their cross sections.

Of these four assumptions, the first and second are commonly satisfied in practice. The third and fourth assumptions, though not always true in practice (for example, structural shapes built up of strap conductor are usually right cornered, whereas structural shapes drawn or rolled in one piece usually have slightly

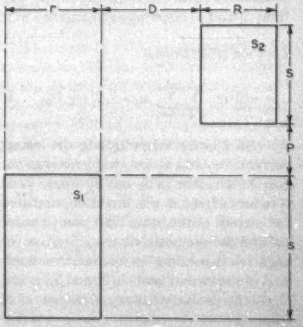

Figure 1

rounded corners; again, skin and proximity effects are always present on a-c busses, though, as Beetz[16] has discussed at length, at power frequencies and normal bus spacings the effect of these phenomena on the magnitudes of the electromagnetic forces is vanishingly small) introduce error negligible with reference to the accuracy required in calculating short-circuit forces and enable solution of an otherwise intractable problem.

If these four postulates are granted, derivation of the desired formulas is not particularly difficult. First, through application of fundamental electromagnetic theory specific formulas are obtained for the components of the electromagnetic force exerted between two conductors, the cross sections of which are *arbitrarily located* parallel-sided rectangular areas. Then these formulas and the same electromagnetic principles are conjoined to obtain general formulas for the components of the force exerted between two conductors, the cross sections of which are arbitrary configurations comprised of parallel-sided rectangular areas (section I). Next, the theory essential to calculation of the derivatives of the geometric mean distances occurring in these formulas is developed (section II). Finally, as the general formulas of section I are applicable to an inclusive category that embraces conductors of structural shape, explicit formulas for the components of the force exerted between conductors of specified structural shape can be deduced from these general formulas as desired (section III).

I. General Formulas for the Components of the Electromagnetic Force

Invoking well-known theory, the inductance L of a circuit comprised of two conductors with rectangular cross sections S_1 and S_2 disposed as in Figure 1 is

$$L = 2 \log (D_{12}^2/D_{11}D_{22})$$

$$= -(2/I^2) \sum_{i=1}^{2} \sum_{j=1}^{2} w_i w_j S_i S_j \log D_{ij} \quad (1)$$

wherein I is the magnitude of the circuit current; w_i and w_j are, respectively, the current densities in S_i and S_j, taken positive for current in one direction, negative for current in the other direction (whence w_i^2 and w_j^2 are positive, $w_i w_j$ positive or negative depending on the relative direction of the two currents in S_i and S_j); and D_{ij} is the geometric mean distance of S_i from S_j.

The energy in the magnetic field associated with the circuit is $W = LI^2/2$; whence equation 1 yields

$$W = -\sum_{i=1}^{2} \sum_{j=1}^{2} w_i w_j S_i S_j \log D_{ij} \quad (2)$$

As is well known, the rectangular components of the electromagnetic force exerted between the two conductors are given by

$$f_x \equiv f_D = \partial W/\partial D; \quad f_y \equiv f_P = \partial W/\partial P \quad (3)$$

Substituting from equation 2 in equation 3 as indicated yields

$$f_D = -\sum_{i=1}^{2} \sum_{j=1}^{2} w_i w_j S_i S_j \partial(\log D_{ij})/\partial D \quad (4)$$

$$f_P = -\sum_{i=1}^{2} \sum_{j=1}^{2} w_i w_j S_i S_j \partial(\log D_{ij})/\partial P \quad (5)$$

If each of the two conductors is comprised of several subconductors connected in parallel, one comprised of m subconductors numbered from 1 to m and the other of n subconductors numbered from $m+1$ to $m+n$, equation 23 of reference 27 yields for the inductance of the circuit

$$L = -(2/I^2) \sum_{i=1}^{m+n} \sum_{j=1}^{m+n} w_i w_j S_i S_j \log D_{ij} \quad (6)$$

As equation 6 is identical with equation 1 except for the difference in the upper limits of the summations, we obtain from equations 4 and 5 by analogy

$$f_D = -\sum_{i=1}^{m+n} \sum_{j=1}^{m+n} w_i w_j S_i S_j \partial(\log D_{ij})/\partial D \quad (7)$$

$$f_P = -\sum_{i=1}^{m+n} \sum_{j=1}^{m+n} w_i w_j S_i S_j \partial(\log D_{ij})/\partial P \quad (8)$$

wherein f_D and f_P are the component forces on a conductor or a specified subconductor according as D and P are parameters locating one conductor with respect to the other or are parameters locating the subconductor with respect to the other $(m+n-1)$ subconductors.

If we have a double circuit comprised of $p+q$ conductors completely *in toto*, one circuit of two conductors being comprised of p subconductors numbered from 1 to p and the other of q subconductors numbered from $p+1$ to $p+q$, the two circuits carrying currents I_x and I_y respectively, equation 26 of reference 27 yields for the mutual inductance of the two circuits

$$M = -(1/I_x I_y)\left[\sum_{i=1}^{p+q} \sum_{j=1}^{p+q} w_i w_j S_i S_j \log D_{ij} - \sum_{i=1}^{p} \sum_{j=1}^{p} w_i w_j S_i S_j \log D_{ij} - \sum_{i=p+1}^{p+q} \sum_{j=p+1}^{p+q} w_i w_j S_i S_j \log D_{ij}\right] \quad (9)$$

As the second term within the braces is a function only of the parameters defining the geometry and relative location of the cross sections of the conductors comprising the circuit carrying I_y; as a similar statement is true for the third term; and as, therefore, both terms are independent of the parameters, say D' and P', used to locate the conductors of one circuit relative to the other, differentiation of the right-hand member of equation 9 yields

$$f_{D'} = -\sum_{i=1}^{p+q} \sum_{j=1}^{p+q} w_i w_j S_i S_j \partial(D_{ij})/\partial D' \quad (10)$$

$$f_{P'} = -\sum_{i=1}^{p+q} \sum_{j=1}^{p+q} w_i w_j S_i S_j \partial(D_{ij})/\partial P' \quad (11)$$

wherein $f_{D'}$ and $f_{P'}$ are the component forces exerted on a bus, a conductor of the bus, or a subconductor of the bus, according as P' and D' are parameters used to locate the bus, a conductor of the bus, or a subconductor of the bus from the like elements of the other bus. If, then, to the component force on a specified conductor or subconductor obtained from equations 10 or 11 we add the corresponding value obtained from equations 7 or 8, which value is the force exerted on the conductor or subconductor by the other like elements of the *same* circuit, we obtain the total force on the specified conductor or subconductor.

In an n-phase system comprised of n distinct conductors, one conductor, say a, can be considered as carrying current I_a (the currents are expressed as complex

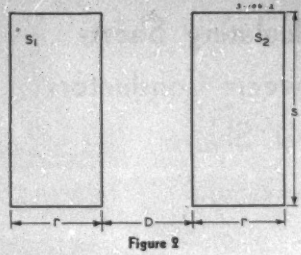

Figure 2

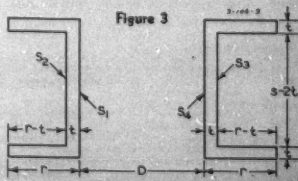

Figure 3

numbers) and the remaining $(n-1)$ conductors can be considered as connected in parallel and carrying the return current. Accordingly, our problem is interpretable as a single-phase circuit comprised of two conductors, one full, the other divided, whence we have from equations 7 and 8

$$f_D = -I_a \sum_{i=b}^{n} I_i \, \partial(\log D_{ai})/\partial D \qquad (12)$$

$$f_F = -I_a \sum_{i=b}^{n} I_i \, \partial(\log D_{ai})/\partial P \qquad (13)$$

wherein P and D are parameters locating S_a with respect to $S_b, \ldots, S_n$.

If the individual conductors are divided, a composed of a' subconductors numbered from 1 to a', b of b' subconductors numbered from $a'+1$ to $a'+b'$, and correspondingly for the others, we have from equations 7 and 8

$$f_D = -\sum_{i=1}^{a'} \sum_{j=1}^{a'+\ldots+n'} w_i w_j S_i S_j \, \partial(\log D_{ij})/\partial D \qquad (14)$$

$$f_F = -\sum_{i=1}^{a'} \sum_{j=1}^{a'+\ldots+n'} w_i w_j S_i S_j \, \partial(\log D_{ij})/\partial P \qquad (15)$$

where now f_D and f_F give the component forces on the entire conductor a or on any subconductor of a, say a', according as D and P are parameters locating conductor a with respect to the other $n-1$ conductors, or are parameters locating subconductor a' with respect to the other $a'+\ldots+n'-1$ subconductors.

With regard to the physical quantities mentioned to this point, all units are in the absolute system: linear dimensions in centimeters, current I in abamperes; self inductance L and mutual inductance M in abhenrys per centimeter of bus length; energy W in ergs per centimeter of bus length; force f in dynes per centimeter of bus length.

Reviewing the analysis of this section, we see that in each case treated the total force, $f = (f_D^2 + f_F^2)^{1/2}$, is determined in both magnitude and direction providing the derivatives indicated in the summations are expressible as known functions of the dimensions of the conductors and bus. Accordingly, we turn now to development of formulas for calculating these derivatives.

II. Calculation of the Derivatives of the Geometric Mean Distances

In earlier papers the writer[27,28] has derived the geometric mean distance D_{12} of a rectangular area S_1 from a second arbitrarily located parallel-sided rectangular area S_2, dimensioned as in Figure 1, to be

$$S_1 S_2 \log D_{12} = -(25/12) S_1 S_2 - (1/24) \sum_{i=1}^{4} \sum_{j=1}^{4} (-1)^{i+j} K(A_i, B_j) \qquad (16)$$

wherein

$$K(A_i, B_j) = (A_i^4 - 6A_i^2 B_j^2 + B_j^4) \times \log (A_i^2 + B_j^2) + 4A_i B_j (B_j^2 - A_i^2) \times \tan^{-1}(B_j/A_i) - 2\pi A_i B_j \qquad (17)$$

and

$$A_1 = |D+R+r|; \; A_2 = |D+R|; \; A_3 = |D|; \; A_4 = |D+r| \qquad (18)$$

$$B_1 = |P+S+s|; \; B_2 = |P+S|; \; B_3 = |P|; \; B_4 = |P+s| \qquad (19)$$

The parameter D in equation 18, and similarly P in equation 19, may be positive, zero, or negative. Thus, if $r = R$, $s = S$, $D = -r$, and $P = -s$, the two areas S_1 and S_2 are identical and superimposed, and equation 16 yields the formula for the self geometric mean distance of a rectangular area. Other more detailed illustrations of application of equation 16 to the determination of the geometric mean distance between two variously located rectangular areas are contained in section V of reference 27 and in section III of this paper.

Turning to calculation of the derivatives indicated in the summations of the preceding section, we have from equation 16 that

$$S_1 S_2 \, \partial(\log D_{12})/\partial D = -(1/24) \times \sum_{i=1}^{4} \sum_{j=1}^{4} (-1)^{i+j} \partial K(A_i, B_j)/\partial A_i dA_i/dD \qquad (20)$$

From equation 17

$$\partial K(A_i, B_j)/\partial A_i = 4A_i (A_i^2 - 3B_j^2) \times \log (A_i^2 + B_j^2) + 4B_j^2 (B_j^2 - 3A_i^2) \times \tan^{-1}(B_j/A_i) + A_i^3 - 3A_i B_j^2 - 2\pi B_j^3 \qquad (21)$$

From equation 18

$$dA_i/dD = d|D + \text{constant}|/dD = \pm 1 \qquad (22)$$

the plus or the minus sign to be chosen according as in a particular problem the specified value of D is such that the quantity within the bars is positive or is negative. Finally, substituting equations 21 and 22 in equation 20 yields the desired formula

$$S_1 S_2 \, \partial(\log D_{12})/\partial D = -(1/24) \times \sum_{i=1}^{4} \sum_{j=1}^{4} (-1)^{i+j} [4A_i (A_i^2 - 3B_j^2) \times \log (A_i^2 + B_j^2)^{1/2} + 4B_j (B_j^2 - 3A_i^2) \times \tan^{-1}(B_j/A_i) + A_i^3 - 3A_i B_j^2 - 2\pi B_j^3] dA_i/dD \qquad (23)$$

Certain variants of equation 23 are of value. If dA_i/dD is of the same sign for $i = 1$ to 4, then

$$\sum_{i=1}^{4} \sum_{j=1}^{4} (-1)^{i+j} A_i^2 dA_i/dD = 2\pi \sum_{i=1}^{4} \sum_{j=1}^{4} (-1)^{i+j} B_j^2 dA_i/dD = 0 \qquad (24)$$

whence equation 23 reduces to

$$S_1 S_2 \, \partial(\log D_{12})/\partial D = -(1/24) \times \sum_{i=1}^{4} \sum_{j=1}^{4} (-1)^{i+j} [4A_i (A_i^2 - 3B_j^2) \times \log (A_i^2 + B_j^2)^{1/2} + 4B_j (B_j^2 - 3A_i^2) \times \tan^{-1}(B_j/A_i) - 3A_i B_j^2] dA_i/dD \qquad (25)$$

Further, if $dA_i/dD = 1$ for $i = 1$ to 4, then

$$3 \sum_{i=1}^{4} \sum_{j=1}^{4} (-1)^{i+j} A_i B_j^2 dA_i/dD = 0 \qquad (26)$$

whence, in turn, equation 25 reduces to

$$S_1 S_2 \, \partial(\log D_{12})/\partial D = -(1/24) \sum_{i=1}^{4} \sum_{j=1}^{4} (-1) \quad U(A_i, B_j) \qquad (27)$$

wherein, for convenience of future reference,

$$U(A_i, B_j) = 4A_i (A_i^2 - 3B_j^2) \log (A_i^2 + B_j^2)^{1/2} + 4B_j (B_j^2 - 3A_i^2) \tan^{-1}(B_j/A_i) \qquad (28)$$

By virtue of the identity, $K(A_i, B_j) = K(B_j, A_i)$ (to be obtained from equation 17 by interchange of A_i with B_j and subsequent use of the trigonometric identity, $\tan^{-1} \quad (A_i/B_j) + \tan^{-1} \quad (B_j/A_i) = \pi/2$), corresponding expressions for $S_1 S_2 \partial \times (\log D_{12})/\partial P$ follow from those for $S_1 S_2 \partial(\log D_{12})/\partial D$ through interchange of A_i and B_j and replacement of D by P. As this operation is easily effected, for economy of space we here set forth only the analog of equation 27:

$$S_1 S_2 \, \partial(\log D_{12})/\partial P = -(1/24) \sum_{i=1}^{4} \sum_{j=1}^{4} (-1)^{i+j} (VA_i, B_j) \qquad (29)$$

wherein

$$V(A_i, B_j) = 4B_j (B_j^2 - 3A_i^2) \log (A_i^2 + B_j^2)^{1/2} + 4A_i (A_i^2 - 3B_j^2) \tan^{-1}(A_i/B_j) \qquad (30)$$

Equations 16 to 30 inclusive suffice for calculation of the derivatives occurring in the double summations defining f_D and f_F. Accordingly, inasmuch as for any given set of data the components f_D and f_F are completely determinable through use of the analysis developed to this point, it follows that this analysis comprises the general solution of the problem of calculating the electromagnetic force, $f = (f_D^2 + f_F^2)^{1/2}$, exerted on a specified conductor or subconductor of a d-c single-phase or polyphase bus comprised of conductors the cross sections of which are arbitrary configurations of parallel-sided rectangular areas.

In general the double summation indicated in the right-hand member of each of equations 23, 25, and 27 is calculated by inserting the numerical values of the parameters A_i and Bj (determined from equations 8 and 9 respectively), obtaining the indicated logarithms and arc tangents from suitable tables, and performing the necessary arithmetic. If, however, it happens—and this case is the rule rather than the exception—that the bus and conductor geometry is such that equation 27 is valid and, further, that therein the summation to be effected is of a form typified by

$$\sum_{i=1}^{4}\sum_{j=1}^{4}(-1)^{i+j}U(A_i, B_j) = \sum_{j=1}^{4}(-1)^{j}F(D, r, B_j) \quad (31)$$

whereof, typically,

$$F(D, r, s) = 2U(D, s) - U(D+r, s) - U(D-r, s) \quad (32)$$

the U functions being those defined by equation 28, the numerical computation can be effected more quickly and with less chance of numerical error through use of the rapidly converging Taylor's series in which the right-hand member of equation 32, considered as a function of D, can be expanded about the point $D=r$; that is, by

$$F(D, r, s) = 12r^3[2s\tan^{-1}(s/D) - D\times \log(D^2+s^2) + (20/12) - Dr^2/6(D_2+s^2) - Dr^4(D^2-3s^2)/90(D^2+s^2)^2 - Dr^6(D^4-10D^2s^2+5s^4)/420(D^2+s^2)^3 - \ldots] \quad (33)$$

The details of this expansion are given in the appendix. Substituting appropriately from equation 33 in equation 31, noting that in the resulting expansion

$$\sum_{i=1}^{4}\sum_{j=1}^{4}(-1)^{i+j}(20/12) = 0$$

simplifying, and then substituting in equation 27 we have

$$S_1S_2\,\partial(\log D_{12})/\partial D = (-1/2)\sum_{j=1}^{4}(-1)^{j}G(D, r, B_j) \quad (34)$$

wherein

$$G(D, r, B_j) = Dr^2[2n\tan^{-1}n - \log(D^2+B_j^2) - m^2/6(1+n^2) - m^4(1-3n^2)/90(1+n^2)^2 - m^6(1-10m^2n^2+5n^4)/420(1+n^2)^3 - \ldots] \quad (35)$$

and $m=r/D$, $n=B_j/D$.

Analogously, if equation 27 holds, we have from equation 28

$$S_1S_2\,\partial(\log D_{12})/\partial P = -(1/2)\sum_{i=1}^{4}(-1)^{i}H(P, A_i, s) \quad (36)$$

wherein

$$H(P, A_i, s) = Ps^2[2m\tan^{-1}m - \log(P^2+A_i)^2 - n^2/6(1+m^2) - n^4(1-3m^2)/90(1+m^2)^2 - n^6(1-10n^2m^2+5m^4)/420(1+m^2)^3 - \ldots] \quad (37)$$

and now $m=A_i/P$, $n=s/P$.

Again, it often happens in practice that the right-hand member of equation 34 reduces to, typically,

$$\sum_{j=1}^{4}(-1)^{j}G(D, r, B_j) = -2G(D, r, s) + 2G(D, r, 0) \quad (38)$$

If so, by virtue of equations 35 and 38, we have from equation 34 the very convenient form

$$S_1S_2\,\partial(\log D_{12})/\partial D = DM(D, r, s) \quad (39)$$

where $M(D, r, s)$ is defined by

$$M(D, r, s) = r^3[2n\tan^{-1}n - \log(1+n^2) + m^2n^2/6(1+n^2) + \ldots] \quad (40)$$

and $m=r/D$, $n=s/D$.

Analogously, from equation 37 we have

$$S_1S_2\,\partial(\log D_{12})/\partial P = PN(P, r, s) \quad (41)$$

where $N(P, r, s)$ is defined by

$$N(P, r, s) = s^3[2m\tan^{-1}m - \log(1+m^2) + n^2m^2/6(1+m^2) + \ldots] \quad (42)$$

and now $m=r/P$, $n=s/P$.

III. Some Illustrative Examples

Example 1 is advanced as corroborative of the preceding analysis. Example 2 is advanced as demonstrative of application of this analysis to calculation of the electromagnetic force exerted between two conductors of structural shape.

Example 1

A single-phase bus is comprised of two identical strap conductors (Figure 2). To calculate the electromagnetic force per unit length:

For this case: $r=R$; $s=S$; $D=D$; $P=-s$; $S_1=S_2=rs$; $w_1=-w_3=I/S_1=I/rs$. Then equations 18, 19, and 22 yield $A_1=D+2r$; $A_2=A=D+r$; $A_3=D$; $B_1=B_3=S$; $B_2=B_4=0$; $\partial A_i/\partial D=1$, $i=1, 2, 3, 4$. From equation 4, noting that the self geometric mean distances, D_{11} and D_{22}, are independent of the parameter D,

$$f_D = -\sum_{i=1}^{2}\sum_{j=1}^{2}w_iw_jS_iS_j\,\partial(\log D_{ij})/\partial D = -2w_1w_2S_1S_2\,\partial(\log D_{12})/\partial D = (2I^2/r^2s^2)S_1S_2\,\partial(\log D_{12})/\partial D \quad (43)$$

By virtue of equations 27, 31, 32, 34, and 39 we obtain

$$S_1S_2\,\partial(\log D_{12})/\partial D = -(1/24)\sum_{i=1}^{4}\sum_{j=1}^{4}(-1)^{i+j}U(A_i, B_j) = -(1/24)\sum_{j=1}^{4}(-1)^{j}[2U(D+r, B_j) - U(D+2r, B_j) - U(D, B_j)] = -(1/24)\sum_{j=1}^{4}(-1)^{j}F(D+r, r, B_j) = -(1/2)\sum_{j=1}^{4}(-1)^{j}G(D+r, r, B_j) = G(D+r, r, s) - G(D+r, r, 0) = (D+r)M(D+r, r, s) \quad (44)$$

wherein

$$M(D+r, r, s) = r^3[2n\tan^{-1}n - \log(1+n^2) + m^2n^2/6(1+n^2) + \ldots] \quad (45)$$

and $m=r/(D+r)$, $n=s/(D+r)$.

Finally, substituting from equation 44 in equation 43 we have

$$F_D = [2I^2/(D+r)][(D+r)^3M(D+r, r, s)/r^3s^2] \text{ dynes per centimeter of bus length} \quad (46)$$

or in units more commonly used: current I in amperes; D, r, s, in inches

$$f_D = [5.4I^2/(D+r)][(D+r)^3\times M(D+r, r, s)/r^3s^2]10^{-7} \text{ pounds per foot of bus length} \quad (47)$$

The dimensionless term in the braces, commonly represented by the symbol k_D, is termed the *electromagnetic space factor* for f_D.

By symmetry the component $f_p=0$. Accordingly, the total force, $f=f_D$, is given by equation 46 or 47. Allowing for the difference of notation, these formulas for f_D agree with those obtained earlier by H. B. Dwight[23] (who first considered this problem) and by the writer.[24]

Example 2

A single-phase bus is comprised of two identical channels placed back to back (Figure 3). To calculate the electromagnetic force per unit length of bus:

Each of the two channels can be considered as comprised of two component conductors: one of full rectangular cross section wherein current exists in the same direction as in the channel, the other of smaller rectangular cross section having current in the opposite direction. Hence $S_1=S_4=rs$; $S_2=S_3=(r-t)(s-2t)$; $w_1=-w_2=w_3=-w_4=I/(S_1-S_2)=I/t(s-2r-2t)$.

From equation 7, noting that the self geometric mean distances, $D_{11}=D_{44}$ and $D_{22}=D_{33}$, are independent of the parameter D, we obtain

$$f_D = -\sum_{i=1}^{4}\sum_{j=1}^{4}w_iw_jS_iS_j\,\partial(\log D_{ij})/\partial D = [2I^2/t^2(s-2r-2t)^2]\,[S_1^2\,\partial(\log D_{11})/\partial D + S_2^2\,\partial(\log D_{22})/\partial D - 2S_1S_2\,\partial(\log D_{12})/\partial D] \quad (48)$$

From equations 18, 19, and 22 we obtain for the three sets of (A_i, B_j) parameters

S_1, S_4: $A_1=D+2r$; $A_2=D+r$; $A_3=D$; $B_1=B_3=s$; $B_2=B_4=0$

S_2, S_3: $A_1=D+2r$; $A_2=A_4=D+r+t$; $A_3=D+2t$; $B_1=B_3=s-2t$; $B_2=B_4=0$

S_1, S_3: $A_1=D+2r$; $A_2=D+r+t$; $A_3=D+t$; $A_4=D+r$; $B_1=B_2=s-t$; $B_3=B_4=t$

The values of the first two derivatives in the right-hand member of equation 48 can be written down by analogy with the value found for the derivative in equation 43. Thus

$$S_1^2\,\partial(\log D_{14})/\partial D=(D+r)M(D+r,\,r,\,s) \tag{49}$$

and

$$S_2^2\,\partial(\log D_{22})/\partial D =(D+r+l)M(D+r+l,\,r-l,\,s-2l) \tag{50}$$

Calculation of the third derivative is effected in precisely the same fashion as in equation 44:

$$\begin{aligned}
&S_1S_2\,\partial(\log D_{14})/\partial D\\
&=-(1/24)\sum_{i=1}^{4}\sum_{j=1}^{4}(-1)^{i+j}U(A_i,\,B_j)\\
&=-(1/24)\sum_{j=1}^{4}(-1)^j[-U(D+2r,\,B_j)+\\
&\quad U(D+r+l,\,B_j)-U(D+l,\,B_j)+\\
&\qquad U(D+r,\,B_j)]\\
&=-(1/24)\sum_{j=1}^{4}(-1)^j[-U(D+2r,\,B_j)-\\
&\quad U(D+l,\,B_j)+2U(D+r+2^{-1}l,\,B_j)+\\
&\quad U(D+r+l,\,B_j)+U(D+R,\,B_j)-\\
&\qquad 2U(D+r+2^{-1}l,\,B_j)]\\
&=-(1/2)\sum_{j=1}^{4}(-1)^j[G(D+r+2^{-1}l,\,r-\\
&\quad 2^{-1}l,\,B_j)-G(D+r+2^{-1}l,\,l/2,\,B_j)]\\
&=(D+r+2^{-1}l)[M(D+r+2^{-1}l,\;\;r-2^{-1}l,s-\\
&\quad l)-M(D+r+2^{-1}l,2^{-1}l,s-l)+\\
&\quad M(D+r+2^{-1}l,r-2^{-1}l,l)+\\
&\qquad M(D+r+2^{-1}l,\,2^{-1}l,\,l)]
\end{aligned} \tag{51}$$

Finally, substitution of equations 49, 50 and 51 in equation 48 yields the desired formula

$$\begin{aligned}
f_D=[2I^2/i^2(s-2r-2l)^2]\{&(D+r)M(D+\\
&r,r,s)+(D+r+l)\;M(D+r+l,\,r-l,\,s-\\
&2l)-(D+r+2^{-1}l)[M(D+r+2^{-1}l,\,r-\\
&2^{-1}l,\,s-l)-M(D+r+2^{-1}l,\,2^{-1}l,\,s-\\
&l)+M(D+r+2^{-1}l,\,r-2^{-1}l,\,l)+\\
&M(D+r+2^{-1}l,\,2^{-1}l,\,l)]\}\text{ dynes per}\\
&\text{centimeter of bus length}
\end{aligned} \tag{52}$$

wherein, typically, $M(D+r,\,r,\,s)$ is given by equation 45.

As by symmetry $f_P=0$, we have $f=f_D$. Inasmuch as the term, electromagnetic space factor, has significance—at least in the sense hitherto employed—only if each of the cross sections of the two conductors possess two principal axes of symmetry, k_D is not to be distinguished. Accordingly, equation 52 encompasses the complete solution of the problem.

Appendix

Consider as a function of D alone

$$F(D,\,r,\,s)=2U(D,\,s)-U(D+r,\,s)-U(D-r,\,s)$$

can be expanded in a Taylor's series about the point $D=r$. Accordingly, by Taylor's theorem we have

$$\begin{aligned}
F(D,\,r,\,s)=&-r^2\partial^2U(D,\,s)/\partial D^2-\\
&(r^4/2\cdot 3!)\partial^4U(D,\,s)/\partial D^4-\\
&(r^6/3\cdot 5!)\partial^6U(D,\,s)/\partial D^6-\ \ldots
\end{aligned}$$

wherein

$$\begin{aligned}
U(D,\,s)&=4D(D^2-3s^2)\,\log\,(D^2+s^2)^{1/2}+\\
&\quad D(D^2-3s^2)\,\tan^{-1}\,(s/D)\\
\partial U(D,\,s)/\partial D&=6(D^2-s^2)\,\log\,(D^2+s^2)-\\
&\quad 24Ds\,\tan^{-1}\,(s/D)+4(D^2-s^2)\\
\partial^2U(D,\,s)/\partial D^2&=12D\,\log\,(D^2+s^2)-\\
&\quad 24s\,\tan^{-1}\,(s/D)+20D\\
\partial^3U(D,\,s)/\partial D^3&=12\,\log\,(D^2+s^2)-44\\
\partial^4U(D,\,s)/\partial D^4&=24D(D^2+s^2)^{-1}\\
\partial^5U(D,\,s)/\partial D^5&=-24(D^2-s^2)(D^2+s^2)^{-2}\\
\partial^6U(D,\,s)/\partial D^6&=48D(D^2-3s^2)(D^2+s^2)^{-3}\\
\partial^7U(D,\,s)/\partial D^7&=-144(D^4-6D^2s^2+s^4)\times\\
&\quad (D^2+s^2)^{-4}\\
\partial^8U(D,\,s)/\partial D^8&=576D(D^4-10D^2s^2+5s^4)\times\\
&\quad (D^2+s^2)^{-5}
\end{aligned}$$

Substitution of the derivatives in the preceding series yields

$$\begin{aligned}
F(D,\,r,\,s)=12r^2[&2s\,\tan^{-1}\,(s/D)-D\times\\
&\log\,(D^2+s^2)+(20/12)-Dr^2/6(D^2+s^2)-\\
&Dr^4(D^2-3s^2)/90(D^2+s^2)^2-\\
&Dr^6(D^4-10D^2s^2+5s^4)/420(D^2+s^2)^3-\ \ldots\ ]
\end{aligned}$$

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Distribution Factors and Pitch Factors of the Harmonics of a Fractional-Slot Winding

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Synopsis: The investigation of the fractional-slot windings with respect to their harmonic (differential) leakage, to noise, and so forth, requires the knowledge of the distribution factors of their harmonics.

Very valuable work on distribution and pitch factors of fractional-slot windings has been done by J. F. Calvert.[1] On the basis of charts he worked out distribution-factor tables covering the actual harmonics up to the 24th. Once the chart of the winding has been set up, a simple formula can be used for computing the distribution factors of the harmonics for any three-phase fractional-slot winding.

In the following paper, simple formulas are derived for the distribution factors of the harmonics of fractional-slot windings which make the layout of charts unnecessary. These formulas are similar to those of the integral-slot windings. In deriving them the usual method of attack, namely, the use of charts, had to be abandoned and the vector diagram of the different slots used instead.

The Actual Harmonics of a Fractional-Slot Winding

IT has been shown in a previous paper[2] that

$$\left(\frac{n'}{p}+1\right)\frac{\beta}{2}=K \quad K \text{ integer excluding } 0 \quad \text{(1a)}$$

and

$$\left(\frac{n'}{p}-1\right)\frac{\beta}{2m_1}=K_1 \quad K_1 \text{ integer including } 0 \quad \text{(1b)}$$

are the criteria for the existence of the n'th harmonic in the magnetomotive force of a fractional-slot winding. (For symbols see nomenclature.)

When the minus sign is used in the equation 1b, the harmonic travels with the rotation; when the plus sign is used, the harmonic travels opposite to the rotation.

Since n' has to satisfy both equations 1a and b, the actual harmonics produced by the winding will be different for different values of β and p. We have to distinguish between the case when β is equal to an even number and the case when β is equal to an odd number. It can be found easily that the actual harmonics of the three-phase windings are as follows:

When β = even number

$$n'=\frac{2p}{\beta}\nu \quad \text{where } \nu=1, 2, 3, 4, 5 \ldots \quad \text{(2)}$$

For the synchronous (main) wave $n'=p$ and, therefore, $\nu_s=\beta/2$. The number of subharmonics is equal to $(\beta-2)/2$.

When β = odd number

$$n'=\frac{p}{\beta}\nu \quad \text{where } \nu=1, 3, 5, 7 \ldots \quad \text{(3)}$$

For the synchronous wave here $\nu_s=\beta$ and the number of subharmonics is $(\beta-1)/2$.

The harmonics which are a multiple of three do not exist in the three-phase machine (except when zero-sequence currents flow in the winding).

The Slot Star

The use of the slot star instead of the generally used chart not only facilitates the layout of the fractional-slot winding but also makes it possible to derive simple formulas for the distribution factor and pitch factor of the harmonics of this winding.

Figure 1 represents the slot star of a winding with an integral number of slots per pole per phase, namely $q=2$. The integral-slot windings can be considered as a special case of the fractional-slot winding having $\beta=1$. Thus each pole represents a repeatable group (a unit) and only one pole has to be considered. The angle between two slots is

$$\alpha_s=\frac{180}{3\times 2}=30°$$

To two adjacent vectors correspond two adjacent slots. The vector 7, with which the next pole starts, is shifted 180 degrees with respect to the vector 1. As regards the synchronous (main) wave, it is taken care of by a proper connection between the coil groups.

We consider now a winding with $1^1/_2$ slots per pole per phase, $q=1^1/_2$. If we write in general

$$q=\frac{N}{\beta} \quad \text{(4)}$$

β poles represent a repeatable group (a unit), each phase has N slots in β poles, and the total number of slots in β poles is equal to $3N$.

In our example two poles make a unit, each phase has three slots per unit, and the total number of slots per unit is equal to nine. The angle between two slots is as before.

$$\alpha_s=\frac{180}{mq} \quad \text{(5)}$$

and it is equal to $180/4.5=40$ degrees. The angles which correspond to the nine slots of the unit are

Slot	1	2	3	4	5	6	7	8	9	10
Angle	0	40	80	120	160	200	240	280	320	360 = 0°

To slot 10 corresponds the angle zero degrees; slot 10 is the beginning of the next repeatable group. Slots 1 to 5 lie under the first pole, slots 6 to 9 lie under the second pole of the unit. Since the connections between the coil groups take into account a shifting of 180 degrees, the real angles between the slots, that is, the shifting of the slots with respect to each other in the magnetic field, are

Slot	1	2	3	4	5	6	7	8	9	10
Angle	0	40	80	120	160	20	60	100	140	180°

and the slot star of the repeatable group is given by Figure 2. Between vectors 1 and 2, which correspond to slots 1 and 2, lies the vector which corresponds to slot 6; between vectors 2 and 3, which correspond to slots 2 and 3, lies the vector which corresponds to slot 7, and so on. The winding creeps in the magnetic field. In general, between two vectors which correspond to two adjacent slots lie $(\beta-1)$ other vectors. We have to distinguish between the angle between

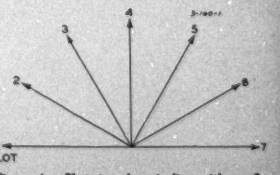

Figure 1. Slot star of a winding with $q=2$

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two slots as given by equation 5 and the angle between two adjacent vectors. This latter angle is the magnetic-field angle between the slots of the repeatable group; this angle determines the behavior of the winding with respect to its magnetomotive force and electromotive force, that is, its distribution factors and pitch factors.

The magnetic-field angle is

$$\alpha_m = \frac{180}{Nm} \tag{6}$$

$\alpha_s = \alpha_m$ only for the winding with an integral number of slots per pole per phase, because for this winding $\beta = 1$ and $N = q$. For the fractional-slot windings α_m is always smaller than α_s. It is

$$\frac{\alpha_s}{\alpha_m} = \beta \tag{7}$$

Apparently, the highest distribution factor for the synchronous wave will be obtained when the first three vectors of the slot star, Figure 2, are assigned to phase I, the following three vectors are assigned to phase II, and the last three vectors to phase III. Thus, in each repeatable group phase I will occupy slots 1, 2, and 6; phase II, slots 3, 7, and 8; and phase III, slots 4, 5, and 9.

We consider the sequence of the slots in the slot star, Figure 2. If we start with slot 1, the sequence of the slots follows the series

$$1, 1+5, 1+2\times5, 1+3\times5 \ldots\ldots$$

Since the total number of slots in the repeatable group is equal to $3\times N$, this value (or a multiple of it) has to be subtracted from the terms of the series when they are larger than $3N$.

In general, the series is

$$1, 1+d, 1+2d, 1+3d \ldots\ldots$$

where d is the difference between two slots which correspond to two adjacent vectors of the slot star.

This difference d can be found from the following consideration.[1] If we denote by P the number of full pole pitches between two slots which correspond to two adjacent vectors of the slot star (in our example $P = 1$), then there will be

$$d\times\alpha_s = \alpha_m + 180P$$

Inserting α_s and α_m from equations 5 and 6 there will be

$$d = \frac{m_1 NP + 1}{\beta} \tag{8}$$

For P the smallest integer for which d becomes an integer has to be inserted. P is equal to or larger than one.

The Distribution Factors of Three-Phase Windings

The slot star Figure 2 relates to the synchronous wave, the length of which is equal to 2τ. With respect to this wave the winding behaves as if there are N slots per pole per phase shifted with respect to each other by the magnetic-field angle α_m, which is equal to the angle between two adjacent vectors. Thus, the distribution factor of the synchronous wave is

$$K_d(n'=p) = \frac{\sin N\alpha_m/2}{N \sin \alpha_m/2} = \frac{\sin 30°}{N \sin 30°/N} \tag{9}$$

In order to determine the distribution factor of the n'th harmonic, it is only necessary to determine the angle between two adjacent vectors of Figure 2 for this harmonic. The number of slots per pole per phase N is the same for all harmonics.

We consider first the wave with the length equal to $2\beta\tau$. With respect to this wave the angle between two slots is,

$$\alpha_{s\beta} = \frac{\alpha_s}{\beta}$$

Since the winding behaves with respect to this wave as a normal integral-slot winding the magnetic-field angle must be equal to the slot angle, that is,

$$\alpha_{m\beta} = \alpha_{s\beta} = \frac{\alpha_s}{\beta} = \alpha_m$$

Figure 3 shows the slot star with respect to this wave. Adjacent vectors lie in adjacent slots. To two adjacent vectors of Figure 2 corresponds here the angle $d\alpha_m$. For example, to the two adjacent vectors 1 and 6 of Figure 2 corresponds here the angle $5\times\alpha_m = d\alpha_m$. Thus, for the harmonic the wave length of which is equal to $2\beta\tau$ the angle between two adjacent vectors of Figure 2 is equal to $d\alpha_m$. It is necessary to add to this angle 180 degrees when P is an odd number, in order to take into account the opposite direction of the current.

When we consider now the fundamental wave ($n' = 1$), the wave length of which is equal to $2p\tau$, the angle between two adjacent vectors of Figure 2 for this wave will be $d\alpha_m\beta/p$ or $d\alpha_m\beta/p + 180$ when P is an odd number. Therefore, the corresponding angles for the n'th harmonics are

$$\alpha_{mn'} = n'd\alpha_m\frac{\beta}{p} \quad \text{(when } P \text{ is an even number)} \tag{10}$$

$$\alpha_{mn'} = n'd\alpha_m\frac{\beta}{p} + 180 \quad \text{(when } P \text{ is an odd number and } \beta \text{ is even)}$$

$$\alpha_{mn'} = n'(d\alpha_m + 180)\frac{\beta}{p} \quad \text{(when } P \text{ is an odd number and } \beta \text{ is odd)}$$

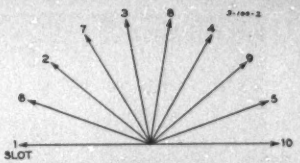

Figure 2. Slot star of a winding with $q = 1^1/_2$ with respect to the synchronous wave

and the distribution factor of the n'th harmonic is

$$K_{dn'} = \frac{\sin N\alpha_{mn'}/2}{N \sin \alpha_{mn'}/2} \tag{11}$$

It can be shown that the numerator of equation 11 is equal to sin 30 degrees for all harmonics which are not a multiple of 3. We apply equations 2 and 3 to equation 10. We find:

When β = even number

$$n' = \frac{2p}{\beta}\nu \qquad \nu = 1, 2, 4, 5, 7 \ldots\ldots \nu_3 = \frac{\beta}{2}$$

and

$$\alpha_{mn'} = 2d\alpha_m\nu + 180 \tag{12}$$

P is here always an odd number: since N is here an odd number, d can become an integer only when P is an odd number.

When β = odd number

$$n' = \frac{p}{\beta}\nu \qquad \nu = 1, 5, 7, 11, 13 \ldots\ldots \nu_3 = \beta$$

$$\alpha_{mn'} = d\alpha_m\nu \quad \text{(when } P \text{ is an even number)}$$

$$\alpha_{mn'} = d\alpha_m\nu + 180 \quad \text{(when } P \text{ is an odd number)} \tag{13}$$

When β is an even number, N and P are odd numbers, d can be an odd as well as an even number, but d is not divisible by three. Thus, with N = odd number and

$$\alpha_m = \frac{180}{3N}$$

$$\sin N\alpha_{mn'}/2 = \sin N(d\alpha_m + 90) = \cos d\nu \times 60°$$

The product $d\nu$ is not divisible by three, therefore

$$\sin N\alpha_{mn'}/2 = \cos d\nu \times 60 = \cos 60° = \sin 30°$$

When β is an odd number, N, P, and d can be even as well as odd numbers; but d is not divisible by three; further, d is an odd number when N or P is an even number, and d is an even number when N and P are odd numbers. We have to consider the cases where P is even and those where P is odd.

When P is an even number, then

$$\sin N\alpha_{n'}/2 = \sin Nd\alpha_m/2 \times \nu = \sin d\nu \times 30$$

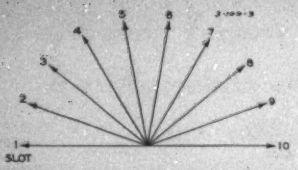

Figure 3. Slot star of a winding with $q = 1^1/_2$ with respect to the wave whose length is equal to $2p\tau$

d and ν are odd numbers, not divisible by three. Thus $d\nu$ is an odd number not divisible by three and

$$\sin N\alpha_{mn'}/2 = \sin d\nu \times 30 = \sin 30 \text{ degrees}$$

When P is an odd number and N is an even number, then

$$\sin N\alpha_{mn'}/2 = \sin N(d\alpha_m/2 \times \nu + 90) = \sin Nd\alpha_m/2 \times \nu = \sin d\nu \times 30$$

and the result is the same as for P equal to an even number.

When P is an odd number and N is an odd number, then d is an even number, and there will be

$$\sin N\alpha_{mn'}/2 = \sin N(d\alpha_m/2 \times \nu + 90) = \sin (d\nu \times 30 + 90) = \cos d\nu \times 30$$

Since $d\nu$ is an even number

$$\sin N\alpha_{mn'}/2 = \cos d\nu \times 30 = \sin 30°$$

Therefore, we can write for equation 11

$$K_{dn'} = \frac{\sin 30°}{N \sin \alpha_n'/2} \qquad (14)$$

$\alpha_{n'}$ is given by equations 12 and 13. Inserting these equations and also equations 6 and 8, we find finally

When β = even number

$$K_{dn'} = \frac{0.5}{N \cos\left(\frac{d}{N} 60\nu\right)} \qquad (15)$$

When β = odd number

$$K_{dn'} = \frac{0.5}{N \sin\left(\frac{d}{N} 30\nu\right)} \quad \text{(when } P \text{ is an even number)} \qquad (16)$$

$$K_{dn'} = \frac{0.5}{N \cos\left(\frac{d}{N} 30\nu\right)} \quad \text{(when } P \text{ is an odd number)} \qquad (17)$$

Equations 15 to 17 are valid for the absolute values only. Equations 10 and 11 yield also the right signs.

EXAMPLES

Three-phase machine with 14 poles and $q = 11/7$. Thus, $N = 11$, $\beta = 7$. Equation 8 yields $d = 19$ with $P = 4$. Since β is an odd number and P an even number, equation 16 has to be applied. It is $p = \beta$ and, therefore, $n' = \nu$ (see equation 3).

It is valid

$$K_{dn'} = \frac{0.5}{11 \sin \frac{19}{11} 30} = 0.058 \text{ for the fundamental wave}$$

$$K_{dn'} = \frac{0.5}{11 \sin \frac{19}{11} 30 \times 5} = 0.0463 \text{ for the fifth harmonic}$$

and so forth.

Eight-pole machine with $q = 11/4$, $N = 11$, $\beta = 4$, $d = 25$ with $P = 3$.

For $2p/\beta = 2$, $n' = 2\nu$ (see equation 2). Thus,

$$K_{dn'} = \frac{0.5}{11 \cos \frac{25}{11} 60} = 0.0625 \text{ for the second harmonic}$$

$$K_{dn'} = \frac{0.5}{11 \cos \frac{25}{11} 60 \times 4} = 0.0457 \text{ for the eighth harmonic}$$

and so forth.

The Pitch Factors of Three-Phase Windings

For the pitch factor of the synchronous wave

$$K_{p(n'=p)} = \sin \frac{W}{\tau} 90 \qquad (18)$$

Denoting by Z the coil width in slot pitches, we can write for the synchronous wave

$$K_{p(n'=p)} = \sin \frac{Z}{mq} 90 = \sin \frac{Z\beta}{mq\beta} 90$$

$$= \sin \frac{Z\beta}{mN} 90 = \sin Z\beta \frac{\alpha_m}{2} \qquad (18a)$$

Referring α_m as in section 3 to the wave the length of which is equal to the total circumference of the armature ($2p\tau$), we find for the pitch factor of the n'th harmonic

$$K_{pn'} = \sin Z\beta \frac{\alpha_{n'}}{2} \qquad (19)$$

$\alpha_{n'}$ is given by equations 12 and 13. As for the distribution factor, it must be distinguished between the case when β is an even number and the case when β is an odd number. Inserting in equation 19 equations 12, 8, and 6 for β = even number, and equations 13, 8, and 6 for β = odd number, we find in agreement with Calvert

$$K_{pn'} = \sin \frac{W}{\tau} \frac{180}{\beta} \nu \quad \text{(when } \beta = \text{even number)} \qquad (20)$$

$$K_{pn'} = \sin \frac{W}{\tau} \frac{180}{2\beta} \nu \quad \text{(when } \beta = \text{odd number)} \qquad (21)$$

Nomenclature

d—difference between two slots which correspond to two adjacent vectors of the slot star.

$K_{dn'}$—distribution factor of the n'th harmonic.

$K_{pn'}$—pitch factor of the n'th harmonic.

m_1—number of phases.

n'—order of the harmonic with respect to a fundamental whose wave length is equal to the circumference of the armature.

N—numerator of the fraction that fixes the number of slots per pole per phase.

p—number of pole pairs.

P—number of full pole pitches between two slots which correspond to two adjacent vectors of the slot star.

$q = \frac{N}{\beta}$—number of slots per pole per phase.

W—coil width.

Z—coil width in slot pitches.

$\alpha_s = \frac{180}{mq}$—angle between two slots.

$\alpha_m = \frac{180}{mN}$—angle between two vectors of the slot star.

β—denominator of the fraction that fixes the number of slots per pole per phase.

τ—pole pitch (in the units of W).

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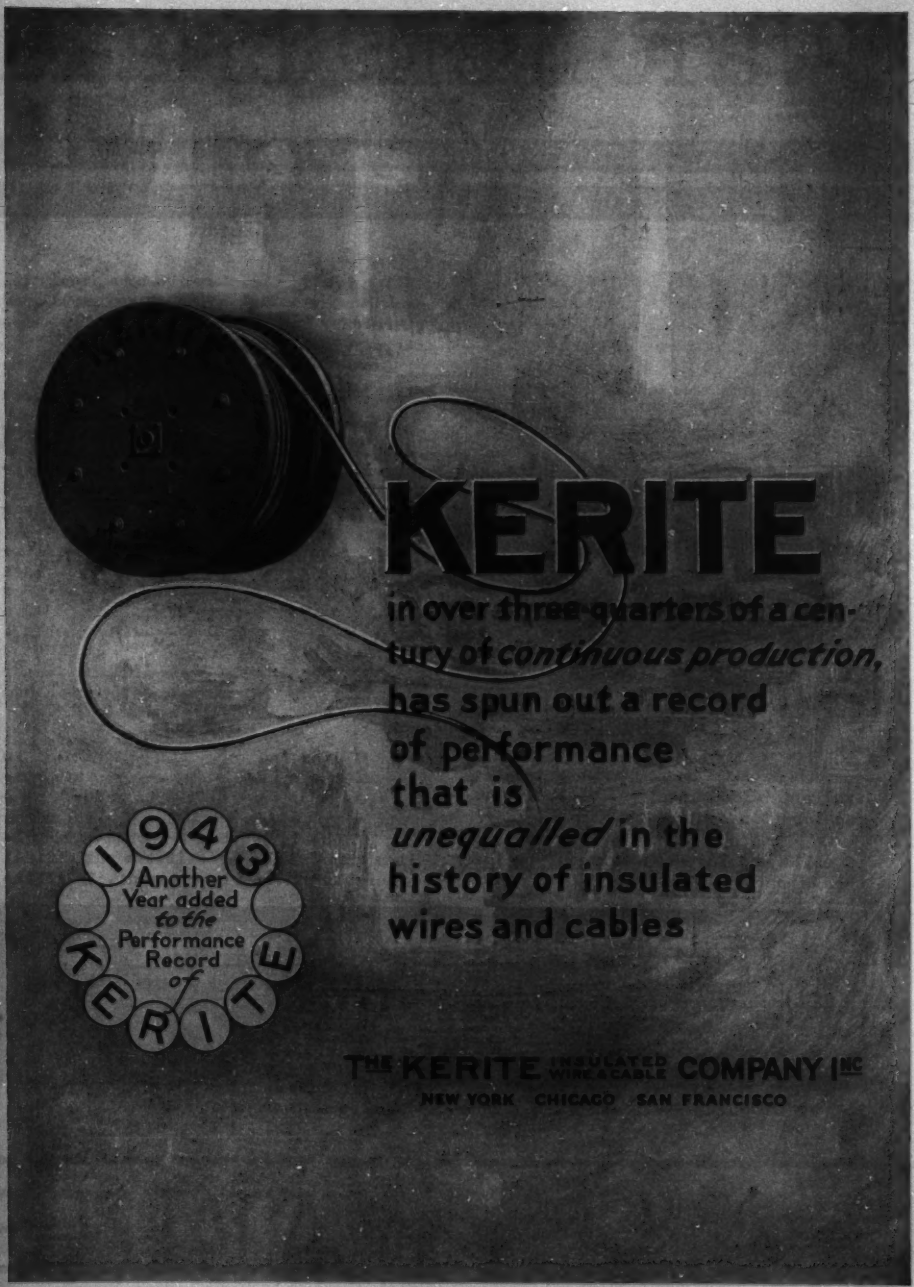
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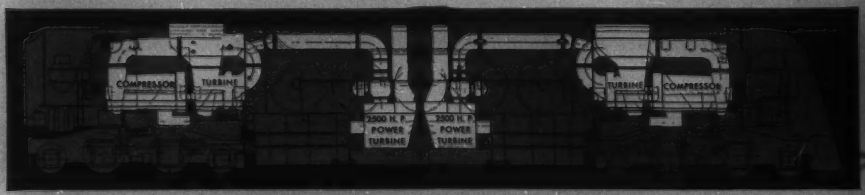

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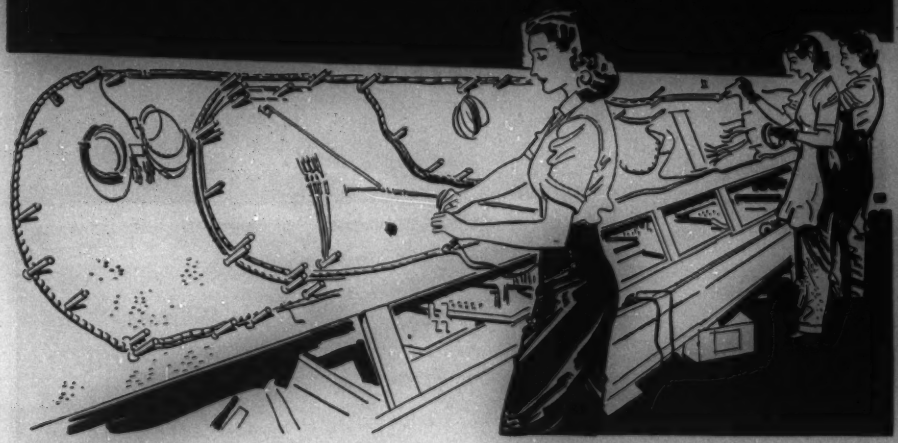

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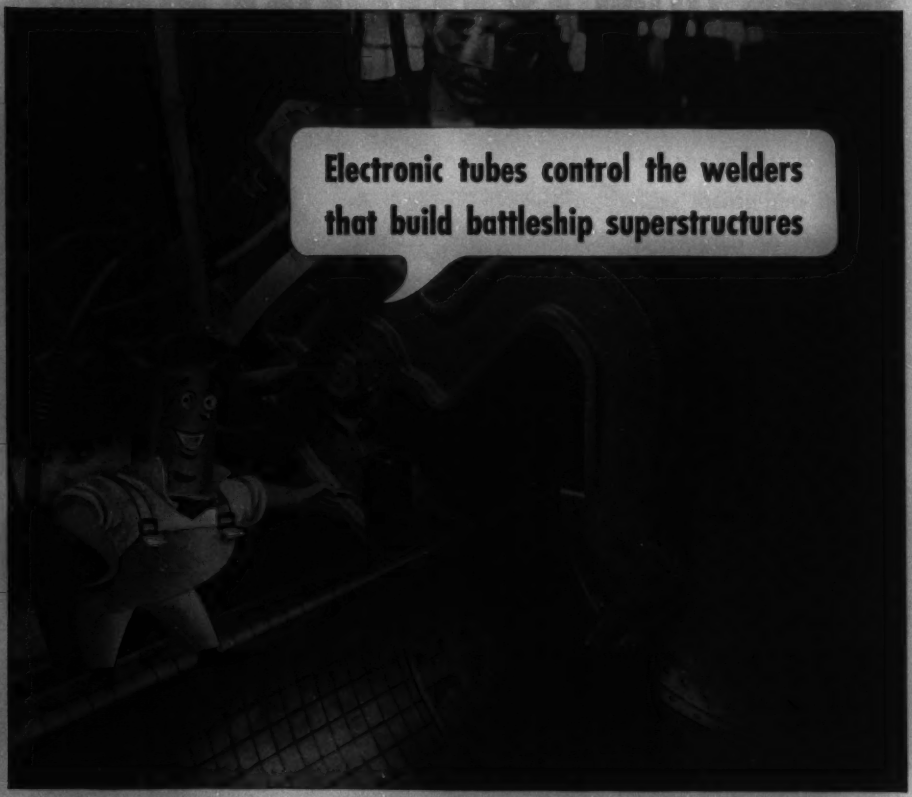

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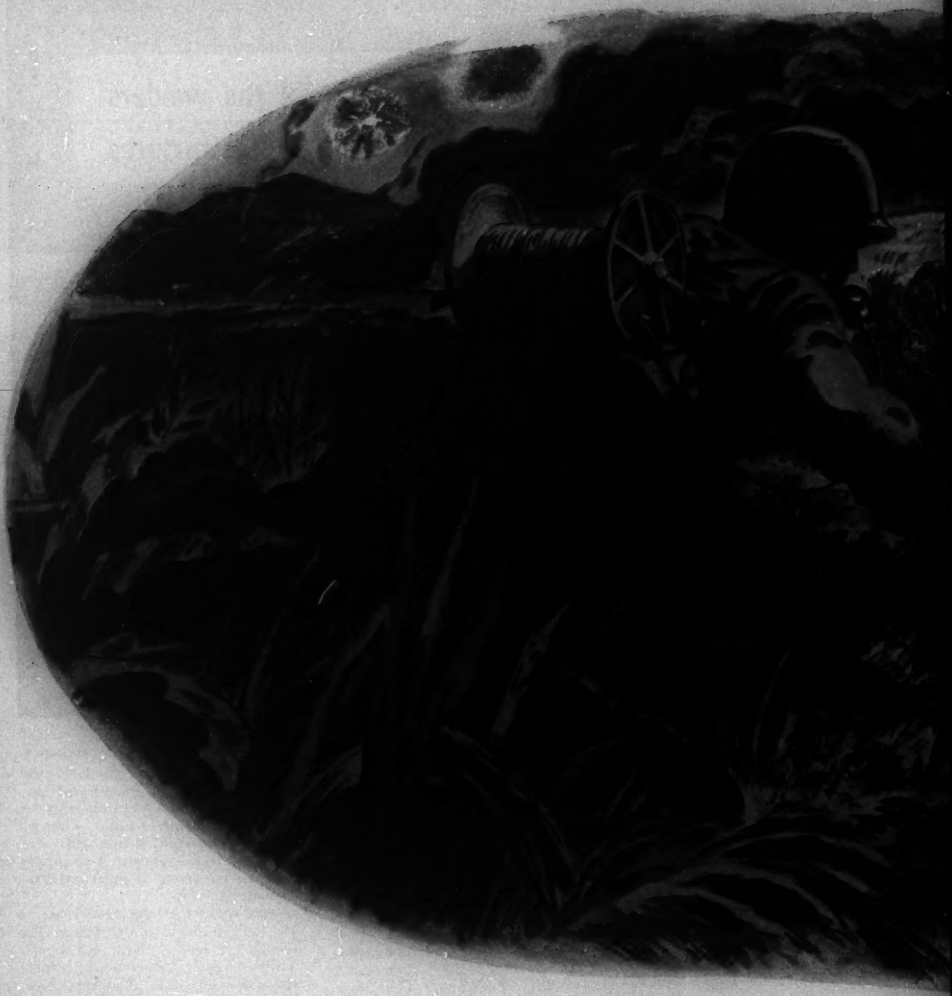

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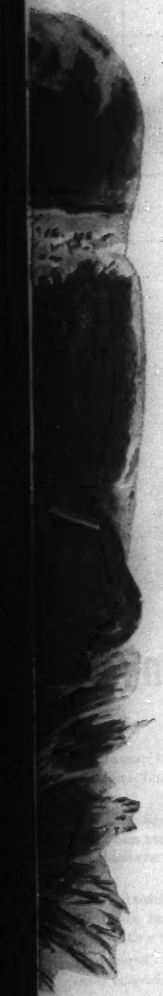

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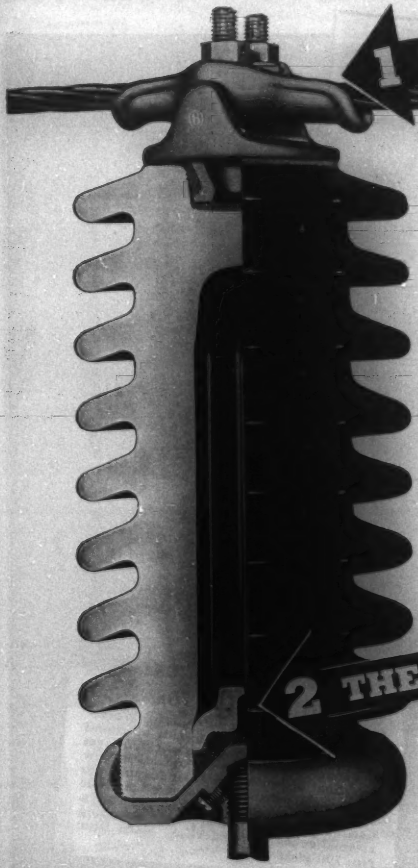


1 THE CLAMPTOP

1 Clamptops, available in 11½-inch and all larger size O-B line posts, eliminate the use of several feet of pure copper tie wire at each insulation point and thus conserve a considerable quantity of highly critical material. This clamp is easily worked with hot line tools. Clamptops are radio-silent and thus re-enforce the inherent good radio qualities of line posts. In addition, the general appearance of Clamptops is extremely neat and goes well with the post-type insulator whose appearance is often some factor in its selection.

2 THE CERAMIC SEAL

2 The good dielectric and radio qualities of line posts depend upon a totally and permanently dry interior cavity. O-B seals this cavity with a ceramic barrier, glazed into place. This barrier is inserted prior to firing of the porcelain. At maximum temperature, the glaze becomes fluid. At this time, most of the air inside has escaped past the barrier. As soon as cooling starts, the glaze sets and completely seals the cavity and traps a high vacuum. Later, the barrier is pierced with a small hole and this vacuum measured in order to prove absolute air-tightness. Dry, inert gas is then pumped into the cavity and the hole re-sealed. The O-B Ceramic Seal is impervious to the passage of air and is not affected by time. Interior of the post remains permanently dry and the unit's electrical characteristics remain permanently stable. No perishable organic material is used to preserve the vital seal in O-B line posts.

Ohio Brass

MANSFIELD, OHIO

CANADIAN OHIO BRASS CO., LTD., NIAGARA FALLS, ONT.

2419-N

Comparative Analysis of 3 Corning Coil Form Methods

	MULTIFORM COIL FORMS	BLOWN COIL FORMS	PRECISION GROUND COIL FORMS
O. D. Diameters	9/16" to 12"	1" to 3"	⅛" to 1½"
Lengths	0.70" to 10½"	2½" to 9"	½" to 6"
Wall Thickness	3/32" to ⅞"	⅛" to ⅜"	3/64" to 3/16"
Maximum Threads per inch	32	12	24
Tolerance	± 2% but not less than ± 0.010" on all dimensions	± 0.015" on root diameter of thread	± 0.002" on root diameter of thread
Holes	Mold formed	Punched or ground	Punched or ground
Metallizing	Yes	Yes	Yes
Types of Glass	No. 790 Only	No. 707 or No. 774	No. 707 or No. 774

Comparative Properties of Corning Coil Form Glasses

	# 790	# 707	# 774
Maximum Operating Temperature (°C)	900	425	500
Linear Expansion (0-300°C) per °C x 10^{-7}	8.5	31	32
Water Absorption—24 hrs.(%)	<.01	None	None
Volume Resistivity log R at 20° C	13.0	17.0	14.7
S.I.C.—20° C—1 MC	4.0	3.95	4.65
P.F.—20° C—1 MC	0.18	0.06	0.42
L.F.—20° C—1 MC	0.72	0.24	1.95

MULTIFORM COIL FORMS

This exclusive Corning Glass Works' method offers coil forms with all-round superior electrical characteristics . . . yet moderately priced in any quantity. Low coefficient of expansion. Most adaptable to complicated shapes or where multiple holes are required. Good thread contours. Can be metallized for applying mounting assemblies or terminal clips. Made from No. 790 glass only.

Pyrex Insulators

"PYREX" is a registered trade-mark and indicates manufacture by Corning Glass Works

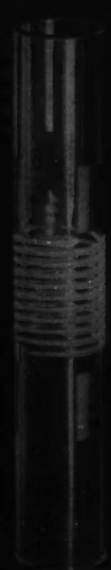
CORNING COIL FORMS EVERY NEED!

2

BLOWN COIL FORMS

In minimum quantities of 12,000 to 15,000 units for No. 774 glass, this Corning method provides coil forms at rock-bottom prices. Forms are unusually strong mechanically and are transparent for easy inspection of internal assemblies. Can be metallized for applying mounting assemblies or terminal clips. Can also be made from No. 707 glass in limited quantities by hand molding, for the duration.

3



PRECISION GROUND COIL FORMS

This method, while slightly more expensive, produces most accurate thread contours. Adaptable to any quantity. Has advantage of transparency. Mountings or terminal clips can be applied by metallizing. Made from either No. 707 or No. 774 glasses.

MAIL COUPON TODAY

Corning Glass Works
Insulation Division, Dept. N10-7
Corning, N. Y.

Please send me the full story on Corning's 3 Coil form methods.

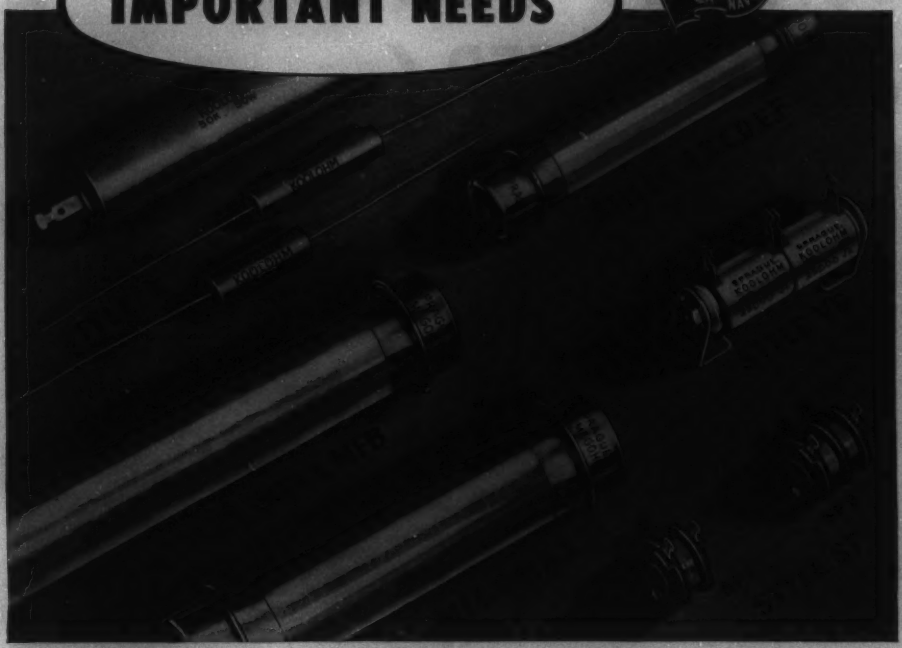
Name.....

Company.....

Street.....

City.....*State*.....

A TYPE FOR IMPORTANT NEEDS



STYLE "K" RESISTORS: Power Wire Wound Resistors 5, 10, 25, 50, and 120 watts.

Wire lead or lug terminals on styles 5K and 10K.

Lug terminals only on styles 25K, 50K, 120K.

Non-inductive windings available.

Various types of mounting, shown in catalog.

STYLES A, B, C, D, E, F: 120, 90, 50, 35, 20, 10 watts.

Hermetically sealed power wire wound resistors. Designed to withstand salt water immersion tests.

Ferrule Terminals for fuse clip mounting.

Non-inductive windings available.

STYLE V. D.: 10 watt and 15 watt wire wound. Resistors designed to make voltage divider sections when mounted end to end on through bolt.

STYLES MFA, MFB and MFC: Precision Meter Multiplier Resistors. Hermetically sealed. Salt water immersion proof.

Type MFA—7.5 megohms max.
Type MFB—4 megohms max.
Type MFC—1 megohm max.

STYLE SP: Wire wound bobbin type resistors. Style SP-1, single section. Style SP-2, dual section.

2.5 watts, continuous rating, per section.

250,000 ohms max. per section.

MEGOMAX: High voltage, high temperature, composition resistor. Hermetically sealed.

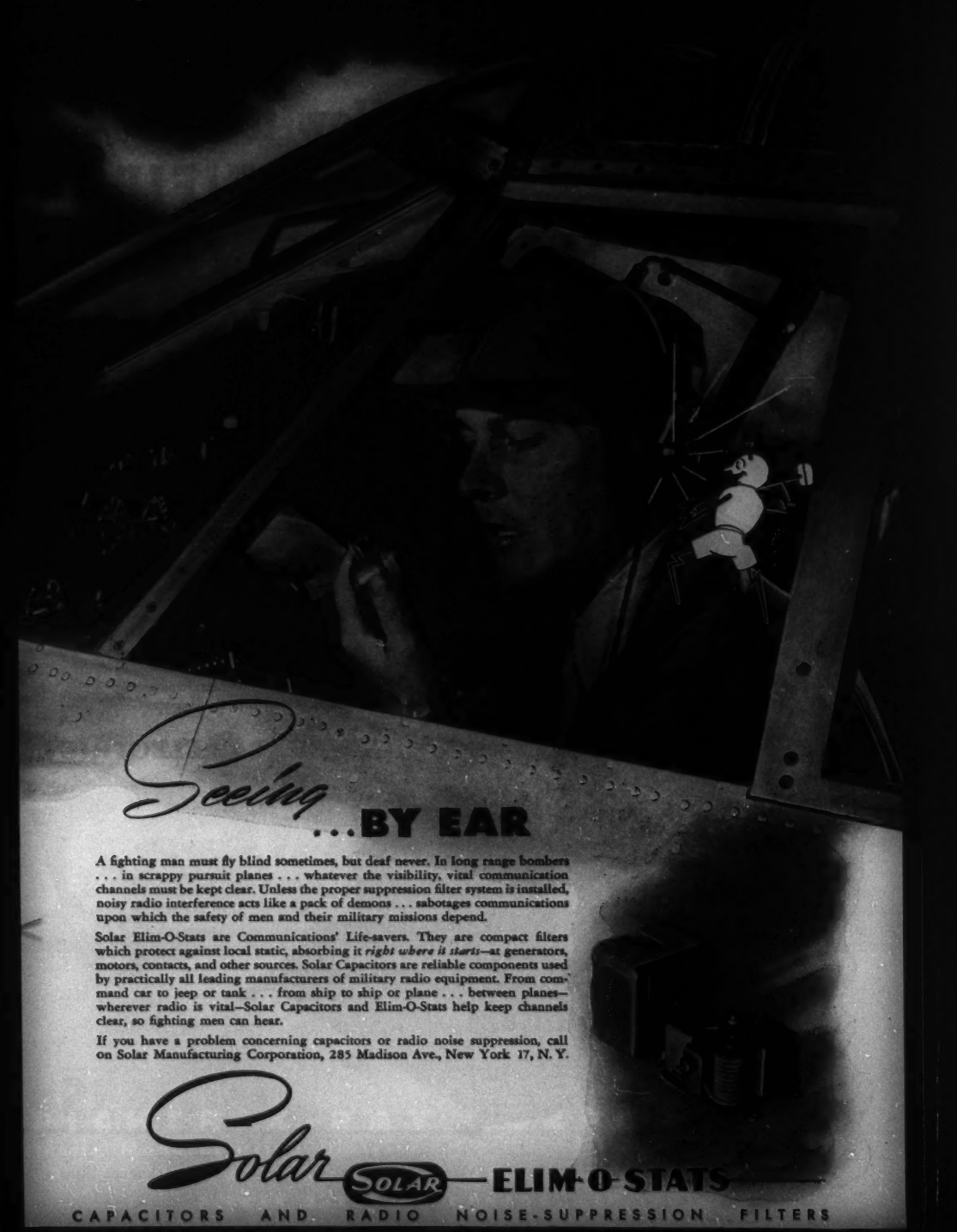
Type 1—3400 ohms to 100 megohms
Type 2—6800 ohms to 100 megohms

Voltage and power ratings depend on resistance value.

SPRAGUE SPECIALTIES CO., Resistor Division, NORTH ADAMS, MASS.

SPRAGUE KOOLOHM RESISTORS

REGISTERED TRADEMARK



Seeing ...BY EAR

A fighting man must fly blind sometimes, but deaf never. In long range bombers . . . in scrappy pursuit planes . . . whatever the visibility, vital communication channels must be kept clear. Unless the proper suppression filter system is installed, noisy radio interference acts like a pack of demons . . . sabotages communications upon which the safety of men and their military missions depend.

Solar Elim-O-Stats are Communications' Life-savers. They are compact filters which protect against local static, absorbing it *right where it starts*—at generators, motors, contacts, and other sources. Solar Capacitors are reliable components used by practically all leading manufacturers of military radio equipment. From command car to jeep or tank . . . from ship to ship or plane . . . between planes—wherever radio is vital—Solar Capacitors and Elim-O-Stats help keep channels clear, so fighting men can hear.

If you have a problem concerning capacitors or radio noise suppression, call on Solar Manufacturing Corporation, 285 Madison Ave., New York 17, N. Y.

Solar SOLAR ELIM-O-STATS

CAPACITORS AND RADIO NOISE-SUPPRESSION FILTERS

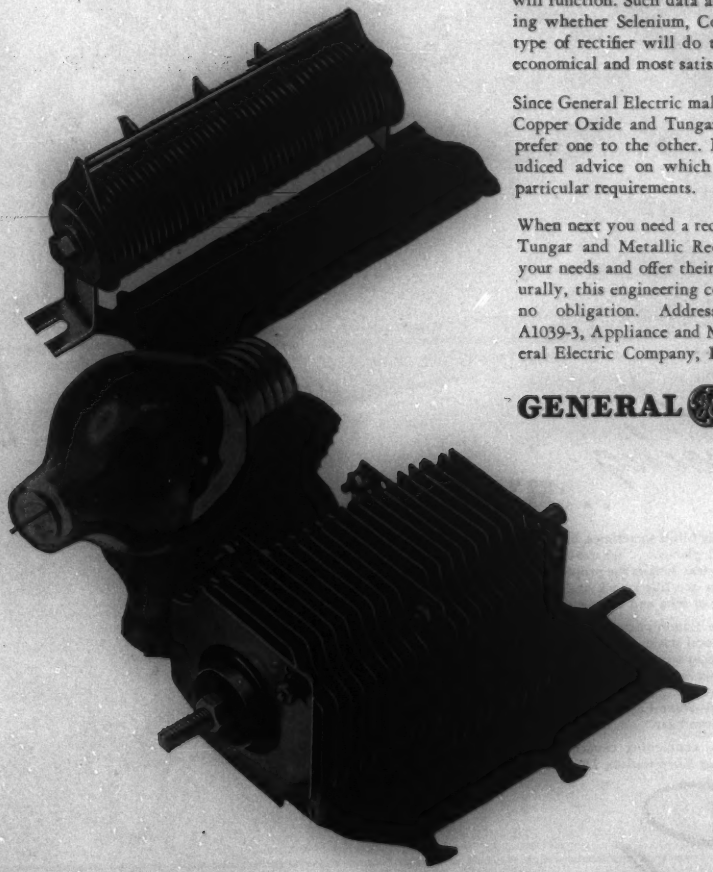
How to Select a RECTIFIER

To say one type of rectifier is better than any other type would be as fatuous as saying a bomber is better than a fighter plane. Each is better than the other when accomplishing the specific results for which it is designed.

Thus, the manufacturer of a product employing rectifiers must first determine the results to be obtained and the conditions under which the rectifier will function. Such data are essential when deciding whether Selenium, Copper Oxide or Tungar type of rectifier will do the most efficient, most economical and most satisfactory job.

Since General Electric makes all three—Selenium, Copper Oxide and Tungar—it has no reason to prefer one to the other. It can give you unprejudiced advice on which type is best for your particular requirements.

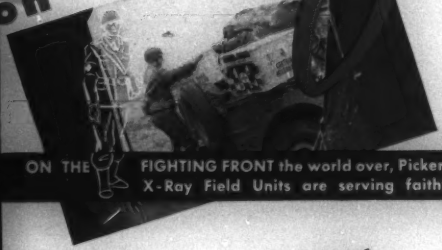
When next you need a rectifier, why not let G-E Tungar and Metallic Rectifier Engineers analyze your needs and offer their recommendations? Naturally, this engineering consulting service entails no obligation. Address inquiries to Section A1039-3, Appliance and Merchandise Dept., General Electric Company, Bridgeport, Connecticut.



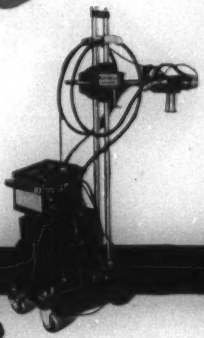
GENERAL ELECTRIC

in the forefront

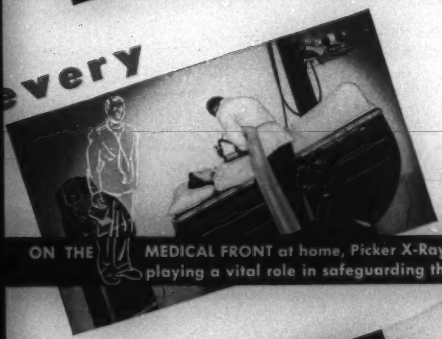
on



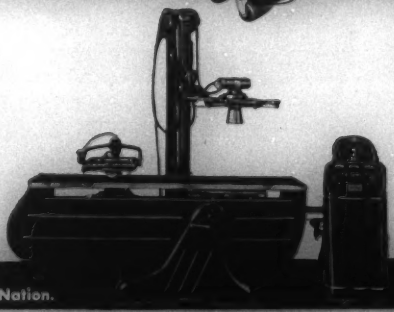
ON THE FIGHTING FRONT the world over, Picker U.S. Army Mobile X-Ray Field Units are serving faithfully, unfailingly.



every

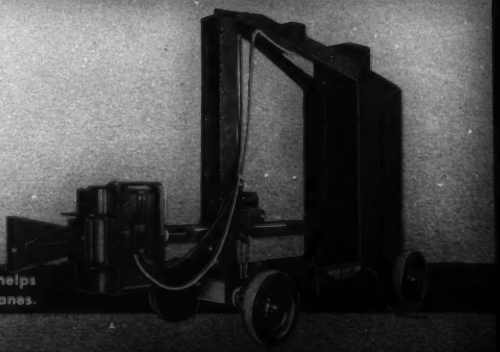


ON THE MEDICAL FRONT at home, Picker X-Ray Apparatus is playing a vital role in safeguarding the health of a Nation.



front

ON THE INDUSTRIAL FRONT Picker Industrial Equipment helps to maintain the mighty surge of ships, tanks, planes.



PICKER

PICKER X-RAY CORPORATION

Waite Manufacturing Division — Cleveland, Ohio

300 FOURTH AVENUE — NEW YORK 10, NEW YORK

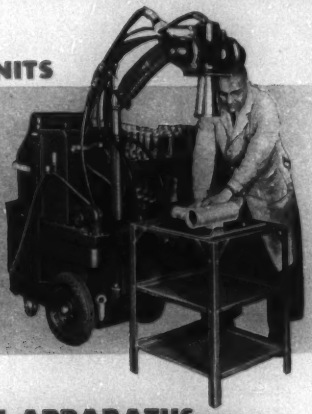
PICKER X-RAY OF CANADA, LIMITED

57 BLOOR ST. W. TORONTO — 758 SHERBROOKE ST. W. MONTREAL

Industry finds Picker X-Ray
Picker X-Ray

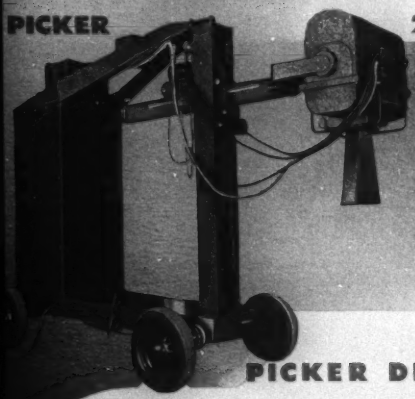
aluable ally in war-time production

PICKER 150 KV INDUSTRIAL X-RAY UNITS



...ratus is a complete ...equipment for plants ...ed at points widely ...itself. Where such ... a stationary version ...graphic inspec- ... conveyor system.

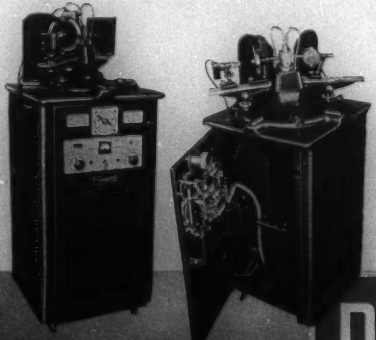
PICKER 250 KV MOBILE APPARATUS



The self-contained ... Industrial Unit finds ... the metal industries. ... ing all necessary equip... tective control boards ... unparalleled flexibility ... heavy castings and ...

PICKER DIFFRACTION EQUIPMENT

Analysis of crystal structure through X-Ray Diffraction Patterns is affording valuable means for the improvement of techniques and materials in many industries. The high standards of precision inherent in Picker Equipment have earned for this Diffraction Apparatus a commanding position in a very exacting field.



PX

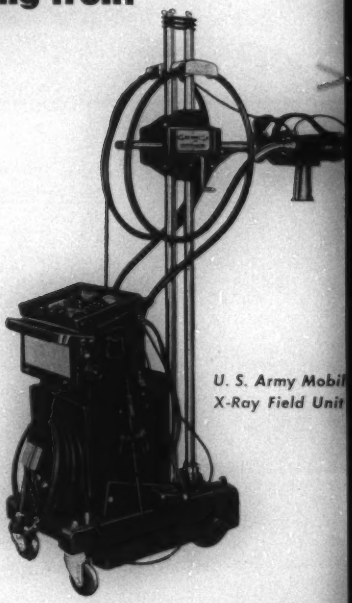
Corporation

wartime role of Picker X-Ray in Medicine

the fighting front

Picker engineers working [illegible] operation with the U. S. Army Medical Department in the development of mobile X-ray Equipment [illegible] used close to front lines.

When Peace [illegible] this country into the conflict the Army Field [illegible] ready when needed. To Picker X-Ray Corporation was entrusted the vital task of supplying these mobile units which are now in operation on all of our far-flung fronts, bringing to hard-pressed front line surgeons X-ray performance of the highest calibre and unfailing dependability. Under conditions which by peace-time standards would seem fantastic, these field X-ray units are operating consistently and dependably . . . in the desert's blistering heat . . . in the Arctic's congealing cold . . . their merit truly PROVEN UNDER FIRE!



U. S. Army Mobile X-Ray Field Unit

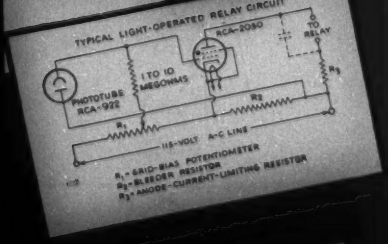
safeguarding health on the home front

Beset on all sides by shortages of equipment and personnel, fewer doctors must carry a greater war time load. Picker X-Ray apparatus is proving its mettle under these crushing burdens . . . and Picker Service Engineers are working night and day, the country over, maintaining essential apparatus at top efficiency.

PX

PICKER X-RAY

Vol. 62
1943



RCA-2050...the Thyratron that started a new trend in electronic control

A THYRATRON is a "trigger" tube—a grid-controlled rectifier—which can "switch" power from full OFF to full ON with a very small change in control voltage.

The RCA-2050, announced in 1939, was a great step forward in thyratron design because it combined unusually high stability and great sensitivity.

Its characteristics were more uniform, too—from one tube to another, from one temperature to another, and throughout the life of any one tube.

Because the RCA-2050 offered such unusual performance, it quickly became a favorite tool of electronics engineers.

And it still is!

Here is a Summary of RCA-2050's Advantages

1. Stability Throughout Life. Characteristics of 2050 change relatively little throughout life of tube.

2. High Power-Sensitivity. Extremely low grid current (less than 0.1 microampere) permits use of high value grid resistor (up to 10 megohms) with consequent high sensitivity. RCA-2050 can be operated directly from a high-vacuum phototube.

3. Little Affected by Line-Voltage Surges. Stability as affected by line voltage surges is high because of the low grid-anode capacitance which results from the use of a shield grid.

4. Extreme Temperature Range. RCA-2050 is unaffected by temperature changes over the range of −50°C to +65°C!

5. All-position Mounting. You can mount the 2050 in any position since it is gas filled and contains no mercury. Its position can be changed during operation.

6. Low Voltage Drop. Xenon filling provides a tube drop of only 8 volts.

7. Quick Warm-up. Ready for operation in 10 seconds after heater is switched on.

8. Low Cost. List price of RCA-2050 is now $1.35, a 62% reduction from its original price.

9. Army-Navy Preferred Type Listing.

Application

The 2050 has found wide application in industrial control circuits. Its high power-sensitivity has made it invaluable as a link between actuating circuits and power circuits eliminating amplifier stages and sensitive relays.

The stability of the 2050 makes possible a high degree of accuracy in timing circuits.

The RCA-2050 is extensively used in control circuits for positioning, for welding, for air-doffer operation, for plastic molding, and as a relay tube in phototube control circuits.

If you have an application problem, RCA application engineers may be able to help you. Write, stating your problem, to Radio Corporation of America, Commercial Engineering Section, 495 South Fifth Street, Harrison, New Jersey.

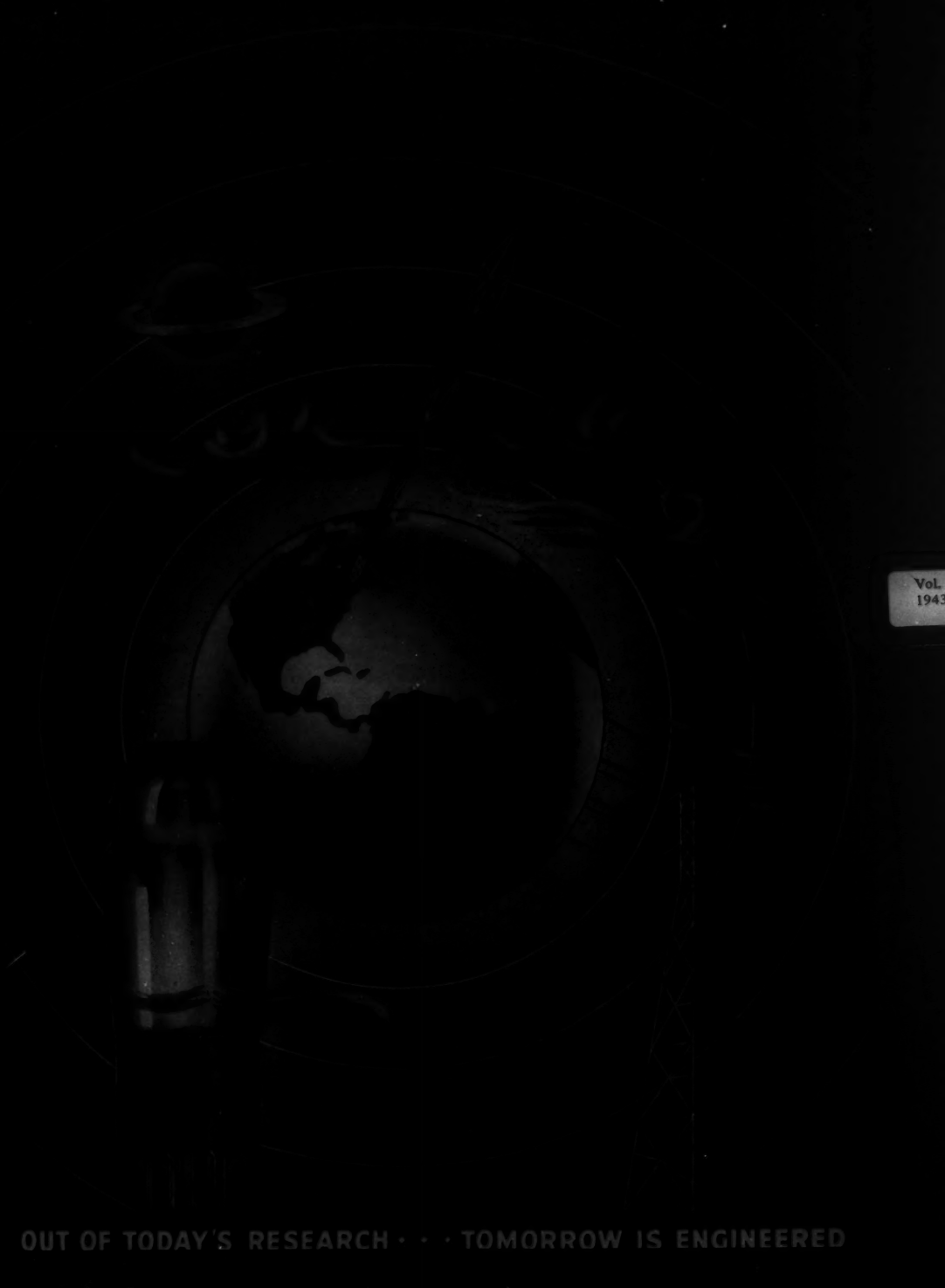
Technical Data

Heater volts, 6.3; heater amperes, 0.6; grid-to-anode capacitance, 0.2$\mu\mu$f; heating time, 10 seconds; maximum overall length, 4½ inches; base, small shell octal 8-pin; peak forward anode volts, 650; peak inverse anode volts, 1300; average anode milliamperes, 100; tube voltage drop, 8 volts.

The Magic Brain of All Electronic Equipment Is a Tube and the Fountain-Head of Modern Tube Development Is RCA.

TUNE IN "WHAT'S NEW?" RCA's great new show, Saturday nights, 7 to 8, E. W. T., Blue Network.

RCA ELECTRON TUBES



Vol.
1943

OUT OF TODAY'S RESEARCH · · · TOMORROW IS ENGINEERED

ECOMING BROADER

SEEING into the impenetrable . . .

Hearing the inaudible . . .

New and amazing industrial processes and controls . . .

Yes, on every side the Horizons are becoming Broader as we enter the Age of Electronics.

Side by side with the achievements in the short- and ultra short-wave field has been the development of ALSIMAG Steatite bodies for high frequency insulators of extremely low dielectric loss together with high mechanical strength and rigidity—assuring constancy under any operating condition.

Today for our fighting forces . . . tomorrow for our customers, American Lava Corporation is pledged to these principles: Production to the highest known standards . . . Research to find a Better Way.

AMERICAN LAVA CORPORATION

CHATTANOOGA, TENNESSEE

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Where stability is an important
equirement, ALSIMAG Steatite
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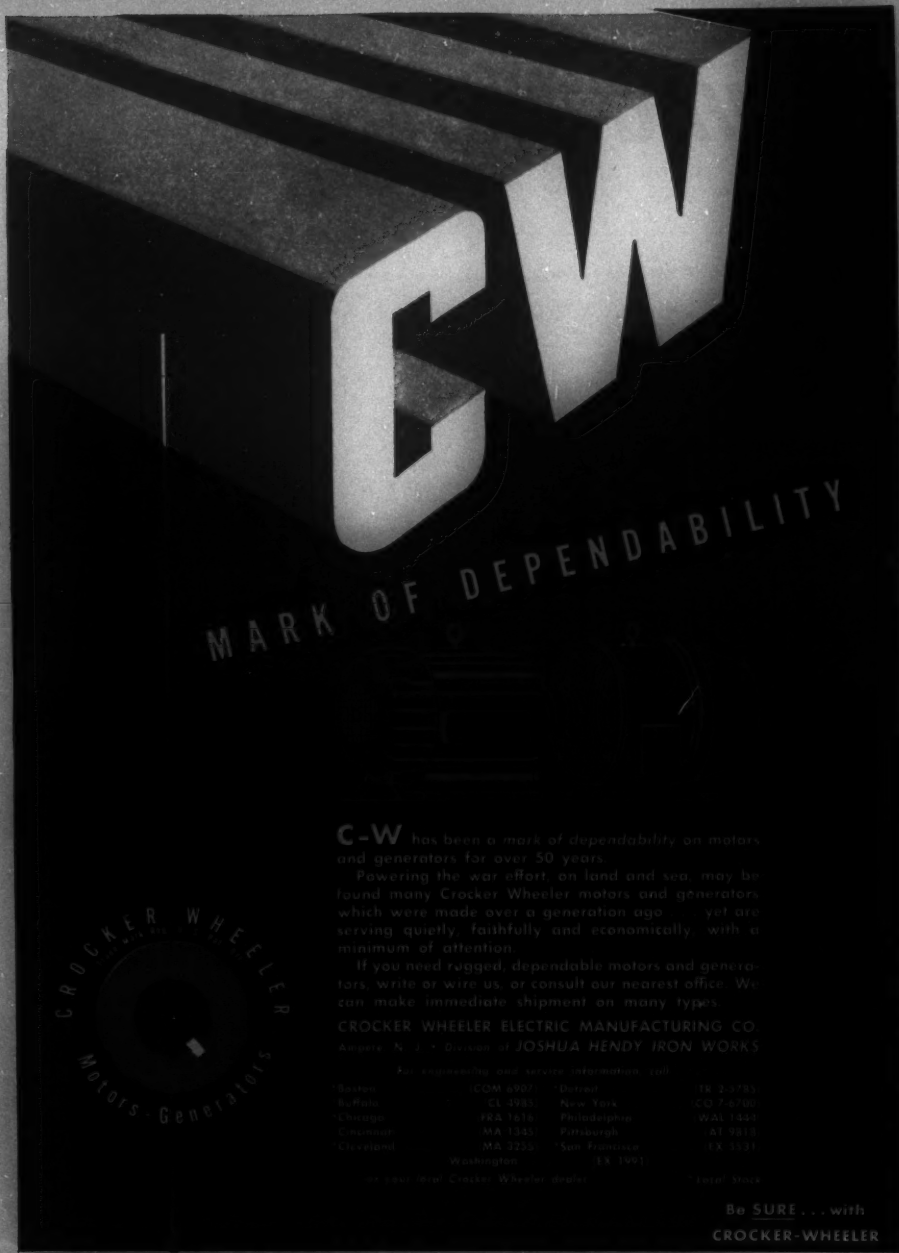
STEATITE CERAMIC INSULATORS

CHARACTERISTICS TAILORED TO YOUR REQUIREMENTS


C-W
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C-W has been a mark of dependability on motors and generators for over 50 years.
Powering the war effort, on land and sea, may be found many Crocker Wheeler motors and generators which were made over a generation ago . . . yet are serving quietly, faithfully and economically, with a minimum of attention.
If you need rugged, dependable motors and generators, write or wire us, or consult our nearest office. We can make immediate shipment on many types.
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NEED HELP FAST?

See your local RCA Tube and Equipment Distributor

— your *Emergency Electronic Expediter*

RIGHT around the corner is a man you ought to know: your own local RCA Tube and Equipment Distributor.

Tackling tough jobs is his business—like locating tubes and other electronic equipment when you need them in a hurry to fill some priority order. For all you know, he probably carries them in stock. Can't hurt to find out anyway—and he may be able to save you a whole lot of trouble and unnecessary delay!

He has the kind of technical "know how", too, that you'll find mighty useful. His angle on how to use a piece of equipment is well worth listening to. Remember, the chances are he's been in radio since its early knee-pants days.

So next time you're stuck for stock, need something electronic in a howling hurry, or find yourself up against something that takes intelligent and tradewise expediting, get in touch *right away* with the man we've picked to serve as your *Emergency Electronic Expediter*.

If you don't know who he is, write us today.

for TECHNICALLY INFORMED SERVICE

NORMALLY ADEQUATE STOCKS

FAST DELIVERIES

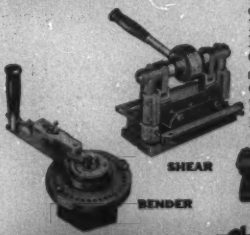
INTELLIGENT EXPEDITING

RCA ELECTRON TUBES

RCA Victor Division • RADIO CORPORATION OF AMERICA • Camden, N. J.

DIE-LESS DUPLICATING

The parts shown are typical of the great variety of simple or intricate forms and shapes which can be quickly duplicated to a tolerance of .001" with DI-ACRO Precision Machines—Shears, Brakes, Benders. For experimental and research work or production runs, DI-ACRO Units form angle, channel, tube, rod, moulding, wire, strip stock; shear stock sheets, trim duplicated stampings. With DIE-LESS DUPLICATING, Man Hours and Critical Materials are saved. Send for 32-page Catalog—"METAL DUPLICATING WITHOUT DIES".



O'NEIL-IRWIN DI-ACRO MFG. CO.

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ELECTRICITY
For Any Job Anywhere

ONAN ELECTRIC GENERATING PLANTS provide electricity for any job anywhere. Complete range of models to cover all applications, mobile or stationary.

Thousands of these reliable, sturdy Plants are doing war winning work on all the fighting fronts.

Sizes from 350 to 35,000 watts. 50 to 800 cycles, 110 to 660 volts, A.C. 6 to 4000 volts, D.C. Also A.C.—D.C. Models.

Your inquiry regarding present or post war needs will receive prompt attention. D. W. Onan & Sons, 1934 Royalston Ave., Minneapolis, Minn.

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Awarded to personnel of all four Onan Plants

Specialists for over a generation in

OIL IMMERSED MOTOR CONTROL

ROWAN CONTROL
THE ROWAN CONTROLLER CO., BALTIMORE, MD.

Perfect INSULATING COMPOUNDS
for a wide range of temperature

In the Northern States, on the Gulf Coast, and both east and west—Minerallac Insulating Compounds are specified . . . proving that these materials do "stand up" no matter what change in temperature may arise.

• WRITE FOR BULLETIN 186 •

MINERALLAC ELECTRIC CO.
25 NORTH PEORIA ST. CHICAGO

If any old transformer will do . . .
ANY MAKE WILL DO!

BUT

If your problem is • Weight, or • Size, or • Precise adjustments, or • Tougher than ordinary electrical characteristics, or • Mechanical requirements, or • Submersion type components, etc. . . .

UTC IS THE LOGICAL SOURCE

MAY WE ASSIST YOU? A note to our Engineering Division will bring a quick response with details on units to your requirements.

UNITED TRANSFORMER CO.
EXPORT DIVISION: 100 VARICK STREET, NEW YORK, N.Y. CABLES: ARLAB

INSTANT

CURRENT MEASUREMENTS

Instantaneously, by merely "snapping" the tongs around any electrical circuit, you can measure the current—BOTH A.C. and D.C. up to 800 amperes—without necessitating a break in circuit or insulation. Every plant electrician should have one. It's a time saver—a production speeder. Weighs only 2¾ lbs. and is as simple to use as the illustration above suggests. Write today for our TONGTEST Bulletin describing its many time-saving applications.

COLUMBIA ELECTRIC MFG. CO.
4519 Hamilton Ave., N.E., Cleveland 14, Ohio

COLUMBIA TONG TEST AMMETERS

No. 1 In a Series of Factors Essential to Maximum Brush Efficiency.

Minimum energy loss is vital in brush operation...

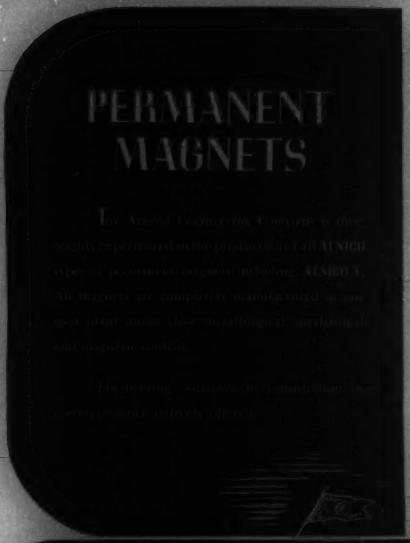
There is more to efficient brush operation than the mere collecting of current. The grade chosen must have the lowest contact drop, frictional loss and resistance consistent with good commutation.

Selection from the all-inclusive Morganite line of electro-graphitic, graphite, carbon and metal-graphite brushes, plus grades especially developed for difficult machines, is your assurance of maximum efficiency.

MORGANITE engineers are available for collaboration. Literature, pertaining to MORGANITE Brushes or Carbon Specialty facilities, will be sent promptly on request. Write to Morganite Brush Company, Inc., Long Island City, New York.

TRADE MARK

MORGANITE BRUSHES



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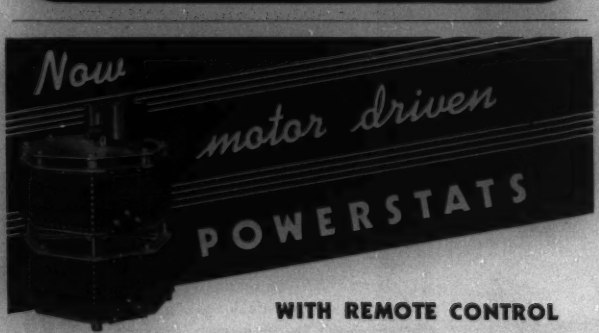

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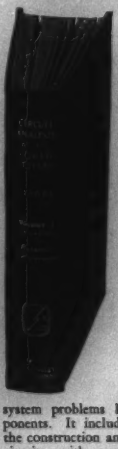

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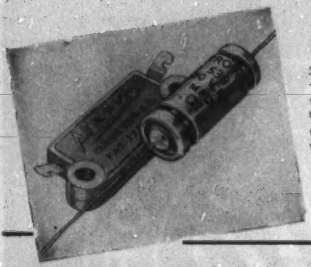

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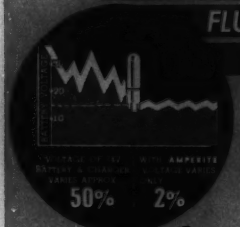

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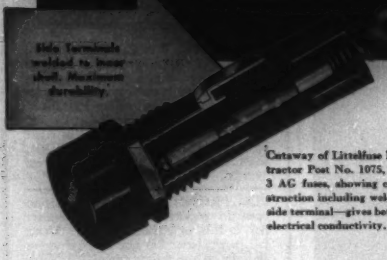

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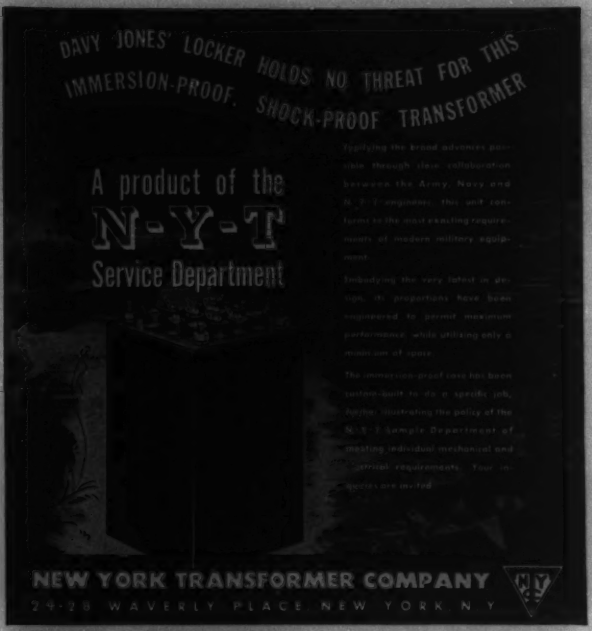
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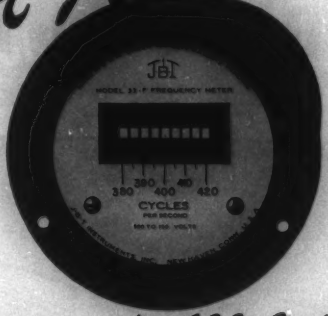

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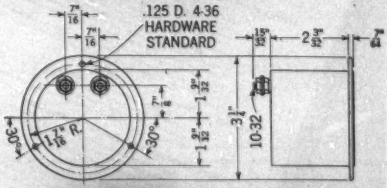

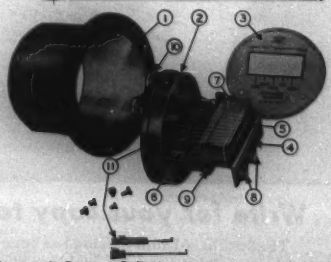

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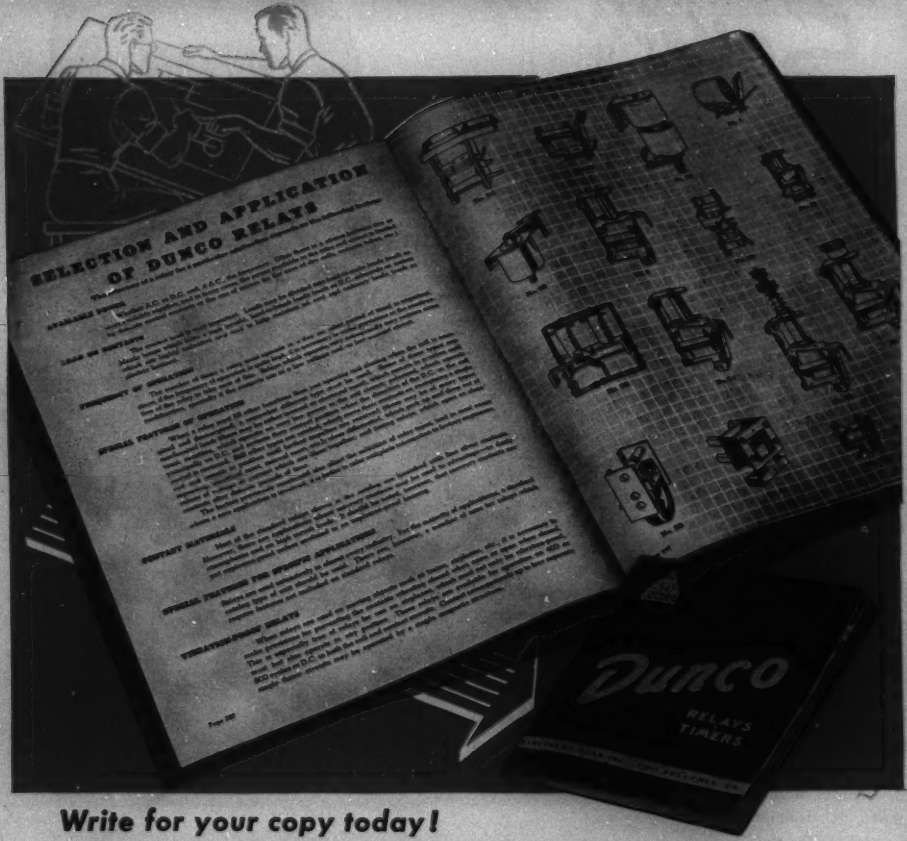

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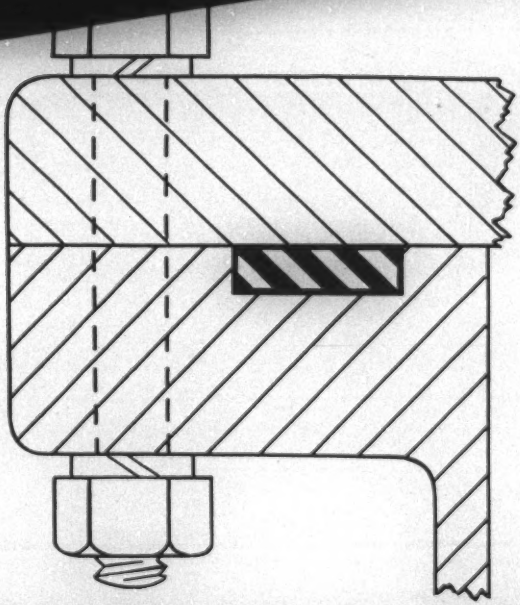

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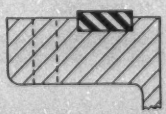

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